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AN ADVANCED KNOWLEDGE AND DESIGN ACQUISITION METHODOLOGY: APPLICATION FOR THE PILOT'S ASSOCIATE (U)

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FOR THE COMMANDER

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This report documents the creation, development, and evaluation of an advanced knowledge and design acquisition methodology. The methodology develops user requirements along three separate yet integrated perspectives: 1) intuitive/experiential knowledge, 2) structural/functional models, and 3) knowledge as design. Three specific tools to implement these perspectives; concept mapping, IDEF modeling, and design storyboarding are discussed. An integrative structure is proposed as an interactive way to let users and other design team members assimilate, deepen, and combine knowledge for the purpose of developing intelligent systems and human-machine interface designs. Hence, system designs are directly derived from "user engineering" and from user conceptualization and participation. The project applies this methodology to the Pilot's Associate program which resolves complex knowledge acquisition/representation requirements. Results indicate that pilots could successfully reveal their own comprehension of an air-to-ground mission and transform this conceptual knowledge into actual designs for an intelligent pilot-vehicle interface. The ability of this methodology to elicit multiple knowledge perspectives and to preserve them in an integrated form (which facilitates interaction with new domain experts in the future) creates an effective means for all phases of the system design.

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SUMMARY

The efforts to integrate artificial intelligence in an advanced tactical fighter (e.g., the Pilot's Associate) are likely to be hampered by two potentially serious, but avoidable shortcomings. The first involves a failure to adequately incorporate multiple pilot perspectives in the design of the system, and the second involves the insufficient breadth of the knowledge-base. Without the inclusion of multiple pilot perspectives, there is a significantly greater risk that the system will fail to address the pilot's information requirements for a tactical fighter mission, and thereby fail to satisfy the pilot's requirement for a Pilot's Associate. Knowledge-based systems which fail to derive common-sense world knowledge, analogies, heuristics, beliefs, and the experience which underlies an expert's performance, run the significant risk of displaying brittleness when confronted with real world performance settings. These issues may be addressed by: 1) providing the PA knowledge engineers with the knowledge elicitation tools necessary to acquire and incorporate multiple pilot perspectives, and 2) developing a large knowledge-base whose breadth and depth are sufficient to handle the complexity associated with the tactical fighter mission.

The research described in this paper is intended to address these shortcomings through the development and utilization of an innovative knowledge and design acquisition methodology that is intended to: 1) highlight the domain expert's conceptualization of the problem domain; 2) identify the information requirements; 3) elicit from the domain expert design prototypes and evolve these design prototypes using the design storyboarding technique; and 4) document the rationale behind the information requirements and design.

The knowledge and design acquisition methodology is comprised of three components, the concept mapping technique, $IDEF_0$ modeling technique and design storyboarding. This paper is chiefly a concept demonstration effort which explores the prospective utility of these techniques.

PREFACE

The research underlying this report was accomplished at the Harry G. Armstrong Aerospace Medical Research Laboratory, Human Engineering Division, Wright-Patterson Air Force Base, Ohio. The work was funded by the Wright Research and Development Center, Cockpit Integration Directorate (WRDC/KT), the Pilot's Associate Program Office, Wright-Patterson Air Force Base, Ohio. The work conducted for this research was in accordance with Work Unit 71841046, Strategic Information and Force Management. The research described in this report was supported by Logicon Technical Services, Inc. (LTSI), Dayton, Ohio under Contract Number F33615 - 89 - C - 0532.

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1 INTRODUCTION

1.0 Background

One of the major research and development projects in applied artificial intelligence today is the DARPA sponsored Pilot's Associate (PA) program. For several years, scientists at the Wright Research and Development Center (WRDC) have been involved in the design of cooperative knowledge-based systems which would culminate in a sophisticated electronic crew member to interact with the pilot during a single seat, tactical fighter mission. The intent underlying the PA program as outlined by Lizza (1989) revolves around the provision of a technology pull for the Strategic Computing program to explore the potential of artificial intelligence to improve mission effectiveness and survivability of advanced fighter aircraft. Within this exploration, there are many technological and programmatic issues which may act as barriers to the eventual flight test of such a system (scheduled for the mid 1990s). One of the most important areas of concern is the myriad of relationships which may develop between the pilot and the associate and the ways in which these relationships are manifest through an interface (i.e., the Pilot-Vehicle Interface).[1]

The psychology of the interaction between the pilot and the associate is a direct product of the design of the PA. Comparatively little attention has been given to this interaction, and as a consequence, there is a distinct possibility that the design of the PA may transpire without recognition of the importance of the pilot's role in the interaction. Before discussing the pilot's requirements, and how they should impact the design process, it is necessary to describe what is meant by a PA.

[1] Several papers have taken directions with respect to such issues. For example, Rouse (1988) addresses the adaptive aiding aspects of human/computer control, McNeese (1986) addresses the 'combined intelligence' of pilots and associates, Snyder & McNeese (1987) analyze conflicts in cooperative man-machine systems, Snyder, Brown, Wellens, and McNeese (1989) discusses the distributed decision making paradigms for studying human-to-human and human-to-intelligent machine relationships, and Wellens & McNeese (1987) review the social psychology of integrating intelligent associates with humans; to cite some of the different directions which have evolved from the seminal PA program.

The PA is being designed as a collection of coupled expert systems to provide real-time assistance to a pilot of advanced single-seat fighters. The PA will organize, filter, integrate, and prioritize data, and then, provide the pilot with essential information, assistance and advice. It will take advantage of artificial intelligence technology with the intention of using a knowledge base that contains the types of knowledge needed to enhance the fighter pilot's performance. It will make use of the symbolic and logical processing capabilities particular to expert systems to assist in the performance of many data analysis and logical decision making tasks presently accomplished by the pilot, as well as some that are currently beyond his or her capabilities. The pilot will be able to call upon the associate for certain function allocation tradeoffs as needed in situations of high stress and workload, and during times of impending lack of situation awareness.

Small, Lizza, & Zenyuh (1989) indicate that the PA contains six cooperating expert systems for pilot decision support which include: the Mission Planner, the Tactics Planner, Situation Assessment, Systems Status, Pilot-Vehicle Interface, and Mission Executive. These systems exchange information as needed and are propagated with changing mission data and the environmental context to support the pilot. Figure 1-1 shows the overall concept of a PA, including the proposed subsystems.

The article by Small, Lizza and Zenyuh (1989) provides an in-depth description of the proposed functionality of each of these subsystems, and should be consulted for further information regarding characteristics of these subsystems. A brief description of each subsystem based on the review by Lizza & Friedlander (1988) is shown in Table 1-1.

1.1 Statement of the problem

In addition to the technical obstacles facing the PA, the efforts to integrate artificial intelligence in an advanced tactical fighter are likely to be hampered by two other potentially serious, but avoidable shortcomings. The first involves a failure to adequately incorporate multiple pilot perspectives in the design of the system, and the second involves the

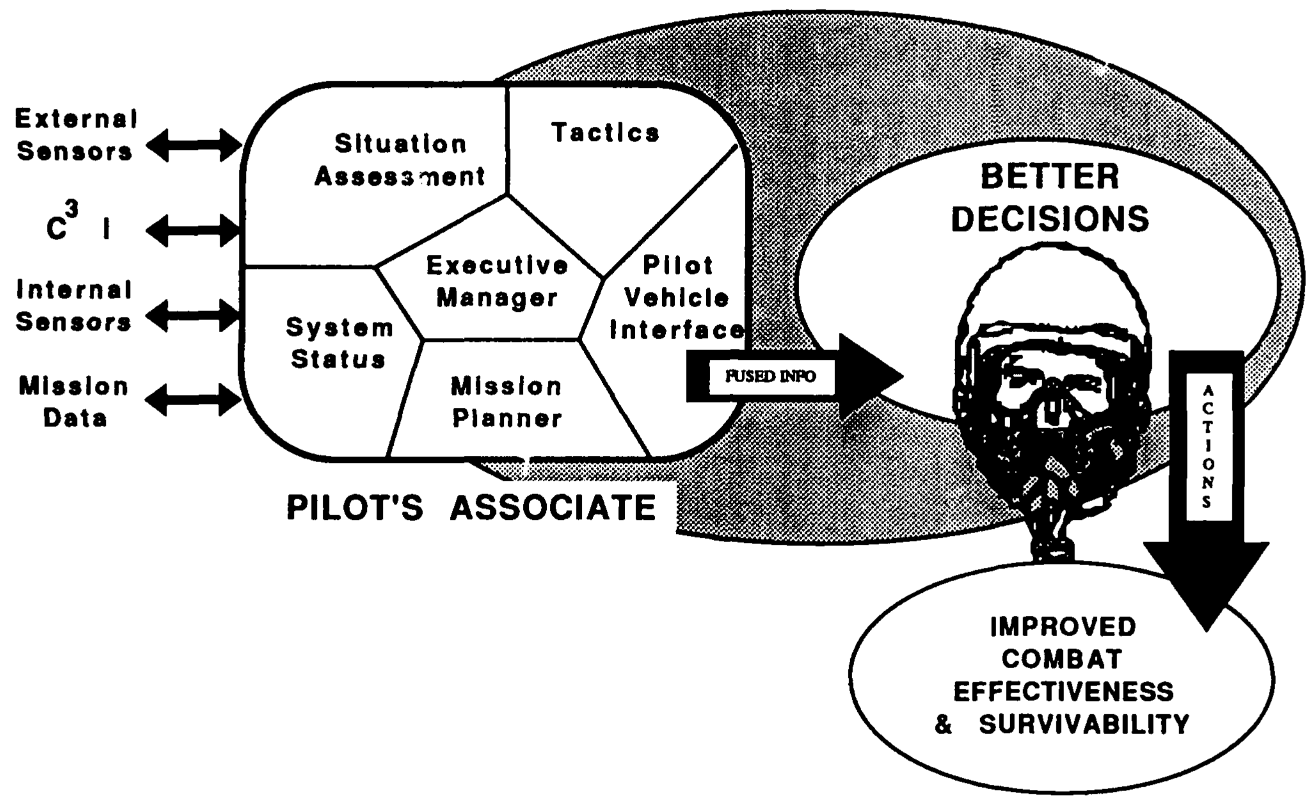


Figure 1-1 PA Architecture

Table 1-1. PA Subsystems

Systems status monitors on-board components to identify, diagnose, and verify system malfunction and to determine the appropriate compensation mechanism.

Situation Assessment provides an accurate and coherent assessment of the type, position, and intent of external entities effecting the planned mission wherein the understanding of threats and prediction of future actions may occur.

Mission Planner compares preplanned mission models with actual events to evaluate the impact of new data and provides a modification of the mission plan as appropriate.

Tactics Planner provides the pilot with specific information and actions (e.g., suggestions of maneuvers, weapons and countermeasure employment, and sensor use) regarding threats and targets and coordinates tactics for multi-aircraft flights.

Pilot-Vehicle Interface is the communications medium between the pilot and the associate in which intelligent computing functions adaptively control the display content and timing, information flow, and allow the pilot to control the associate dependent on assessment or estimation of workload, cognitive resources, pilot preferences, and inferred pilot intent.

Mission Executive is responsible for ensuring the smooth operation and control of the PA through the use of high-level conflict resolution, resource allocation, global strategy development, and task scheduling for real time operations; it also maintains the mission blackboard as the message center of the PA. Taken together, these cooperating expert systems provide the functions and structures for the PA architecture.

Note that the PA is being designed to be included as a real time, on-board associate. Taken together, these cooperating expert systems provide the functions and structures for the PA architecture.

creation of coupled expert systems with insufficient breadth and depth of the resultant knowledge base.

Given the tremendous complexity involved in the design and implementation of the PA's architecture, it is easy to become preoccupied with attempts to solve the technical issues, and lose sight of the pilot's perspective on the system requirements. Lizza (1989), in a review of the current status of the PA program identified knowledge acquisition as an area of major concern, with his recognition that the existing approach was running the risk of failing to adequately incorporate the pilot's perspective. He suggested that although knowledge acquisition needs to be well disciplined and carefully structured, the prior efforts which have adopted a top-down knowledge acquisition approach, were basically flawed to the extent that the elicitation process has produced knowledge which cannot be implemented using classical rule-based or frame-based approaches to expert system design. Lizza goes on to suggest that what is needed is a bottom-up, scenario-driven approach to knowledge acquisition that establishes a context and framework for eliciting knowledge through interviews. Recognition of the deficiencies regarding methodologies used for knowledge acquisition served as the original impetus for our research efforts. These efforts are directed toward the development of an integrated knowledge acquisition methodology and the establishment of an advanced user requirements analysis and synthesis framework for the Pilot-Vehicle Interface (PVI).

The second shortcoming currently facing the Pilot's Associate program involves the creation of coupled expert systems whose architecture consists of a collection of narrow, task-specific problem solvers. As a consequence, the expert systems will generally attempt to finesse intelligence in areas where knowledge: 1) is weak and ill-defined, 2) is not elicited in depth from the domain experts, 3) is captured without sufficient inter-connectivity or contextual indexing, and 4) is under-represented (i.e., large cases of understanding are not developed). Lizza & Friedlander (1988) concluded that the next major hurdle for the contractors implementing the PA is the acquisition of large volumes of knowledge from experts. It is our belief that the development of the PA must be based upon the pilot's ability to: 1) match situations and adjust slightly (**remembrance**), 2) match far flung situations (**analogize**), 3) fall back on general knowledge (**use common sense**), and 4) learn more about situations (**recursion**); (adapted from Lenat & Guha, 1990). The attributes to supplement these abilities must be designed into the PA system from a pilot's perspective. Knowledge-based systems must utilize common-sense world knowledge, analogies, heuristics, beliefs, and the experience which underlies an expert's performance, or they run a significant risk of displaying brittleness when confronted with real world performance settings.

Our efforts to develop a new knowledge acquisition methodology have focused on the premise that a development project such as the PA Program must proceed from the pilot's conceptualization of his or her mission. This conceptualization must direct the development of the PA, and the thoughts, ideas, or hunches (i.e., intuitive knowledge), as well as the experiential knowledge of the pilot must be explicitly identified and shared with the other members of the design team. Without the inclusion of multiple pilot perspectives within the PA design, there is a significant risk that the system will fail to address the pilot's information requirements for a tactical fighter mission, and thereby fail to satisfy the pilot's requirement for a Pilot's Associate.

In addressing the shortcomings facing the PA program, we have pursued the development and evaluation of knowledge acquisition tools that are designed to capture the pilot's comprehension of the tactical fighter mission. Our intention is to incorporate multiple knowledge representation techniques, as well as automating portions of the knowledge acquisition process in order to facilitate the rapid collection, organization, and analysis of the inputs from numerous pilots.

1.2 Uncovering the Expert's Knowledge

The efforts outlined in this report are directed at providing a methodology that can be used to identify the user's requirements for the PA/Pilot-Vehicle Interface. This methodology is intended to be useful for uncovering the pilot's understanding of the mission by focusing on the pilot's intuitive and experiential knowledge which often fails to appear in more structured forms of knowledge representation. To the extent that this methodology has been applied during this initial concept demonstration phase, it will enable the developers of a Pilot's Associate to satisfactorily answer the following questions: 1) What information does the pilot expect to get, when, in what form, and by whom? 2) When and what must the pilot anticipate doing with the information in order to accomplish the mission goals? 3) How should the function allocation vary given changing situations? 4) How should the pilot communicate with the associate? McCormick (1964) restates these issues as he suggests that "in terms of design considerations, it is necessary to anticipate who (or what) is to 'talk' to whom (or what) and to provide for an appropriate link to make this happen" (p. 10).

The design of the pilot's associate has not proceeded without various attempts to capture the pilot's knowledge regarding the fighter mission. Unfortunately these efforts have generally relied upon a top-down knowledge acquisition approach (i.e., mission or task decomposition) and resulted in a highly structured knowledge representation. Often these attempts are taken from the engineer's or analyst's viewpoints, and although deriving specific mission requirements, they fail to adequately represent the pilot's <u>own</u> conceptualization of his mission. In fact, some of the potential problems currently facing the PA development, as identified by Lizza (1989), may be a direct consequence of basing the design of this AI system on the engineer's and analyst's understanding of the vehicle, environment and mission rather than upon the intended user of this domain. It is our belief that the PA/Pilot-Vehicle Interface must successfully meet the user's requirements, and must therefore be based on the user's understanding of vehicle, environment, mission, and associate.

In an effort to deal with the shortcomings in the area of knowledge acquisition, and to adequately elicit the user's perspective of the problem domain, an approach was developed to extract both general and specific knowledge from pilots for a mission segment appropriate to the PA program objectives. The intent was to continually evolve the PA system design requirements on the basis of this acquired knowledge. Specifically, the efforts described in this report involve: 1) the identification of the key decision points and information requirements from the pilot's perspective, and 2) the construction of Pilot-Vehicle Interface design storyboards. Both of these efforts involved the use, and subsequent integration, of several "handcrafted" knowledge acquisition techniques. The projected payoffs from the application of these knowledge acquisition techniques in an integrated methodology include: 1) an expanded identification of information required for the pilot to make decisions/actions; 2) specific knowledge pertaining to situation awareness (i.e., where the pilot is focusing his attention during various points in the mission); 3) a basis for function allocation between the pilot and the associate; and 4) a framework for designing and evaluating interface prototypes. These efforts will eventually culminate with the creation of an automated knowledge acquisition system which will be capable of generating an in-depth knowledge base to counteract some of the inadequacies previously associated with brittle expert systems.

In addition to meeting the PA program's need for an innovative knowledge acquisition methodology, our research efforts are intended as a direct response to the recently published DOD Critical Technologies Plan (1990). This plan was provided to congress as part of an overall Science and Technology investment strategy derived from the National Military Strategy, published by the Joint Chiefs of Staff, the Defense Planning Guidance, and the Office of the Secretary of Defense.

The first critical technology our research effort supports is *Critical Technology No.4, Machine Intelligence and Robotics* which lists knowledge acquisition, knowledge representation, automated reasoning, improved man-machine interfaces, and training as the major challenges facing this area. The issues that our research address are heavily entwined with such challenges. The second critical technology which our research supports is *Critical Technology No. 5, Simulation and Modeling*. This plan encourages the application of Artificial Intelligence and object-oriented programming to create easy and affordable simulations and computer-based models that mimic the behavior of real objects. The plan references the potential payoff of simulation and modeling, including the behavioral modeling of crew performance and the development of computer-aided decision support systems as a means of addressing human factors issues in the combat environment. Additionally, the plan emphasizes: 1) the role of virtual prototyping as an effective method of visualizing system components in an effort to reduce costs and deliver the final product in a quicker time frame; 2) new weapon systems design (including human factors and training considerations via computer simulations) for the purpose of determining design effectiveness, learning constraints, and cognitive overload considerations; and 3) the creation of new design practices to permit experimentation prior to full-scale development of a new system.

Our use of integrated knowledge acquisition and representation techniques, as well as storyboard prototyping, within an object-oriented design environment meets the vision described in this DOD plan. Our agenda for future developments in the areas of automated knowledge and design acquisition technology are directly integrated with the critical technologies mentioned.

1.3 Knowledge Acquisition Techniques

Knowledge acquisition techniques take many different forms. In fact, classifying and categorizing the myriad of techniques and tools has been the focus of attention for several investigators (Boose, 1989; Hoffman, 1987; Bloomfield and Shalin, 1989; Mitta, 1989; Boehm-Davis, 1989). As it is not possible to discuss all the available tools and methods that have been used or developed to elicit expert knowledge, we will limit our discussion to the specific direct and indirect methodologies that could be used in the present context. That is, techniques that rely on direct interaction with the knowledge engineer, those that rely on introspection on the part of the domain expert, and those that emphasize the domain characteristics of naturalistic decision-making in dynamic environments will be of particular interest.

1.3.1 Direct Methods

Direct methods of knowledge acquisition include techniques in which experts are required to report experiences in using a system or accomplishing a particular task. Interviews (structured or unstructured), verbal protocols, and questionnaires fall into this category. In a generic sense, these direct knowledge acquisition strategies are the techniques of primary interest because of their frequent use in domains that are characterized by natural decision making in a dynamic environment.

Structured interviews involve asking experts specific questions about the problem domain of interest. Questions may take the form of rules, procedures, object relationships, etc. In this case, the knowledge engineer must first construct these questions from his/her own knowledge base. The information may come from system documentation, rules of engagement, or procedural documentation. For a structured interview, the knowledge engineer must have a fairly complete understanding of the domain in order to develop the necessary set of queries to acquire the expert's knowledge. It is generally agreed that the quality of the data collected is highly dependent upon the amount of domain knowledge that the knowledge engineer possesses. The domain expert's task is limited to the confirmation and/or correction of information in response to direct questions.

Unstructured interviews have an open-ended format. The knowledge engineer probes specific areas of interest in response to the domain expert's description of the task or system. Presumably, the knowledge engineer also has, at least, a working knowledge of the domain in question in order to probe particular areas of interest and to allow for interpretation of the information the domain expert is producing. In addition to requiring a considerable degree of sophistication on the part of the interviewer developing questions, both structured and unstructured interview techniques, because of their reliance upon the questions that the knowledge engineer generates, run the significant risk of biasing the knowledge acquisition process.

Verbal protocol techniques are examples of unstructured interviews which attempt to avoid the biases that are generated by the knowledge engineer's particular line of questioning. In these techniques, the domain expert is encouraged to "talk through" a task or procedure, and to describe what is 'going through his or her mind' as he or she is performing the task. The elicitation of expert knowledge by verbal protocol consists of the domain expert verbally articulating the sequence of events of a task with which he or she is engaged. With the use of a verbal protocol technique, some of the decision processes that are occurring as the task is being accomplished are captured in the domain expert's verbalizations. These verbalizations are recorded for detailed analysis at a later date.

There are a number of verbal protocol techniques, including Method of Familiar Tasks, Limited Information Tasks, Constrained Process Tasks, and Method of Tough Cases (see Hoffman 1987), that have a common characteristic. The domain expert is asked to report directly on his or her experiences in accomplishing a specific task. The Method of Familiar Tasks involves an analysis of the tasks that the expert usually performs. What the expert knows is typically represented in terms of prepositional statements that are meaningfully related to the domain in question. The Limited-Information Task involves a variation of the Familiar Task approach, in which the domain expert is asked to perform a familiar task that has been manipulated so as to limit the available data. The assumption regarding this manipulation is that with a limited amount of information the domain expert will be forced to decompile and reason about what would otherwise be a highly automated mental process. Constrained Processing tasks also utilize and manipulate familiar tasks. However, the manipulation typically involves the imposition of time constraints or resource limitations. Method of Tough Cases is yet another variation of verbal protocol technique. In this case, however, the expert verbalizes procedures while accomplishing a non-routine or unusual occurrence of a familiar task.

While the verbal protocol techniques may successfully avoid the introduction of the knowledge engineer's biases as a consequence of the questions that are being asked, they do have several other inherent shortcomings. First, these techniques often are used to elicit knowledge that the domain expert is likely to have difficulty articulating due to the fact that much of the knowledge is tacit in nature (Polany, 1966). Tacit knowledge is learned by watching or doing, as opposed to being taught by verbal instruction. Second, and perhaps more serious, is the fact that the obtrusiveness of these techniques may have a major impact on the task strategies, by altering the typical expression of the expert's behavior. Additional problems may occur involving the process of interpreting the verbalizations. The process is extremely time consuming, and runs the unfortunate risk of re-introducing knowledge engineer biases due to the fact that the knowledge engineer is prone to interpret the domain expert's comments from her/his own frame-of-reference.

A variation of the Method of Tough Cases is the Critical Decision Method (CDM) which uses a set of cognitive probes to determine the basis for situation assessment and decision making during non-routine incidents (Klein, Calderwood, and MacGregor, 1989). In contrast to the verbal protocol techniques in which the experts try to articulate the task and decision processes as they occur, the CDM relies on interviews with domain experts that examine recent cases of interest. The recent cases of interest are non-routine incidents, rather than tasks that occur regularly. This probing of specific incidents is said to result in data that are superior in kind and quality to that gained eliciting knowledge about general rules or procedures (Klein et. al.,1989). While the CDM may provide knowledge of appreciable depth, the focus on non-routine decisions that occur in the course of dynamic situations, runs the risk of failing to acquire a sufficient breadth of knowledge. Like the various verbal protocol techniques, the expert would be limited to a single occurrence of a task and, therefore, the efficiency of the knowledge acquisition efforts would be reduced.

1.3.2 Indirect Methods

Indirect techniques include observational studies, simulations and other unobtrusive methods that note and analyze response patterns. Number of responses, errors, and latency of response are the type of data collected in these cases. These types of techniques do not rely on verbalization or discussion with the knowledge engineer during task action or decision making. Therefore, there is less likely a chance that interference will affect the strategies or reasoning processes of the domain expert. However, only inferences about tacit knowledge, strategies, and processes can be made with indirect techniques. Therefore, missing or misleading expert knowledge may result.

1.4 Requirements for an Integrated Knowledge Acquisition Methodology

A commitment to elicit knowledge from the domain expert and to codify that knowledge in an intelligent system does not however, in and of itself, insure that the domain expert's perspective and understanding of the problem domain will be faithfully represented. Highly structured techniques and those relying principally upon informed access run the significant risk of biasing the domain expert's presentation and recall of knowledge. Informed access refers to situations in which the domain expert's knowledge is elicited as a function of the knowledge engineer's probes rather than being spontaneously accessed by the expert (i.e., uninformed access).[2]

A knowledge acquisition process that begins with informed access is likely to elicit information from the domain expert that is in concordance with the knowledge engineer's prior conceptualization of the problem domain. Since the knowledge engineer directs the knowledge acquisition process by informing the domain expert of the information desired, the information elicited from the domain expert is likely to be a reflection of what the knowledge engineer considers to be important, rather than a faithful representation of the relevant information and predominant issues from the domain expert's perspective. When the knowledge acquisition process begins with, or relies exclusively upon techniques that involve either structured or unstructured questioning of the domain expert, the risk of biasing the outcome is significant. Informed access creates a knowledge acquisition setting which may be artificially constrained in that it fails to capture the expert's own neccssity to recall knowledge as needed without being informed to do so (as is often the case in real world settings).

In contrast, uninformed access involves the unprompted elicitation of the concepts that are used by the domain expert, and which arise from his or her own unbiased perspective of the concepts associated with the problem domain. Uninformed access allows the presentation of pilot knowledge to arise directly from his experience with the problem domain. The distinction between informed and uninformed access can be understood in relation to a courtroom proceeding in which the informed access is analogous to a situation where the trial lawyer is leading the witness, and uninformed access is analogous to the presentation and recall of an unbiased eyewitness testimony. In a courtroom setting there would

[2] See Perfetto, Bransford, & Franks, 1983; Adams, Kasserman, Yearwood, Perfetto, Bransford, & Franks, 1988 for research relating to constraints on knowledge acquisition and access.

undoubtedly be a difference between the veridicality of the two testimonies, and likewise, in the field of knowledge acquisition there is a difference between the degree to which the knowledge engineer biases the domain expert's presentation when using the two different approaches.

The intent of distinguishing between informed and uninformed access, is to point out the risks associated with the usage of informed access interview techniques as the <u>sole</u> method of knowledge acquisition. To elicit an unbiased representation of the expert's understanding of the problem domain, the knowledge acquisition procedure should begin by first eliciting the <u>concepts that are spontaneously accessed</u> by the domain expert under uninformed conditions.

There is a distinct value gained by probing the domain expert for details and greater depth of knowledge, and the knowledge acquisition process cannot be confined to a method that employs only an uninformed access to domain knowledge. Rather, a method must be employed that utilizes both informed and uninformed access. The knowledge acquisition process should begin with an uninformed access, to insure an unbiased presentation of the concepts that the domain expert considers to be important. As the elicitation process continues there will be more opportunity for direction and structure to be provided by the knowledge engineers (e.g., specific probes) thereby creating a setting of informed access. Once the domain expert has had the opportunity to thoroughly discuss his or her understanding of the problem domain, it becomes in essence 'safe' for the knowledge engineer to begin probing for additional information without a significant risk of biasing the concepts that are presented.

1.5 An Integrated Knowledge Acquisition Framework: Knowledge as Design

Highly structured task decompositions (e.g., goal/task analysis) have been widely used as a means of deriving a detailed description of the domain expert's behavior. In many instances, structured task decompositions have been utilized as the sole means of eliciting domain knowledge. Although such techniques generally provide means of representing an important aspect of the domain expert's interaction with the system, they fail to adequately capture the domain expert's perspective of the problem space. Because such techniques merely provide a description of the domain expert's overt behavior, it becomes the responsibility of the knowledge engineer to interpret the behavior and provide the cognitive basis for its occurrence. These highly structured techniques do not typically elicit the expert's conceptualization of the problem domain, and cannot by themselves provide an adequate representation of the domain expert's knowledge.

In order to elicit both general and specific knowledge, and succeed in developing a large-scale multidimensional knowledge base, the knowledge acquisition technique must capture more than simply a detailed description of the behaviors that the expert exhibits while operating in the specified problem domain. The knowledge acquisition technique must, in addition, be capable of eliciting the problem definition, the information requirements and the expert's solutions to the problem from the domain expert's perspective.

Structured task decomposition and the method used to elicit the expert's conceptualization of the problem domain provides different views of the user's expertise. Yet, the transfer of knowledge from the domain expert to the knowledge engineer will remain incomplete unless it also includes an exchange of information which has enabled the domain expert to make perceptual discriminations which are relevant to problem solving and felicitous behavior within the problem domain. As a person develops expertise in a given domain, he or she comes to rely upon highly differentiated patterns or attributes perceived from the environment in order to be able to successfully guide his or her actions.[3] Consequently, as the individual begins to develop expertise, decisions and actions are based more on recognition, and less upon reasoning.[4] Knowledge acquisition techniques must go beyond the acquisition of explicit and objective knowledge, and must go beyond a mere verbal description of an expert's

[3] This will not be true of all problem domains, but is likely to be especially true of the tactical fighter environment.

[4] See Klein (1989) for a discussion of recognition based decision making.

pattern recognition processes. It is not enough to simply encourage the expert to verbalize the perceptually salient attributes by asking the domain experts to identify the perceptual attributes to which they have attended. Knowledge that has been derived from experience rather than taught using language is difficult to verbally express. Both the tacit nature of the information (Polany, 1966), and the existence of a mismatch between the knowledge acquisition context and the context during which the perceptual learning is displayed makes it unlikely that this mere encouragement will facilitate the spontaneous access to this information.

When the knowledge engineer tries to elicit expert knowledge within the confines of a verbal discourse, the expert is forced to rely exclusively upon mental simulation to spur recognition of experiential knowledge. This is likely to severely curtail the amount and accuracy of the information that is elicited as the expert attempts to translate tacit knowledge and perceptual learning into a verbal domain. When, however, the knowledge acquisition tools provide the domain expert with the proper medium (i.e., a medium more closely approximating the natural context in which the knowledge is used), the transfer of tacit knowledge and perceptual learning can be facilitated. To the extent possible, a knowledge acquisition technique should provide a perceptual context which can, as much as possible, simulate the conditions under which the domain expert would typically make use of the perceptual learning that he or she has accumulated. With this ecological connection, the bottleneck problem will be reduced, and much of the intuitive and experiential knowledge will be spontaneously accessed.

Although the pilot's conceptualization of mission requirements have been woefully absent in many models and/or descriptions; it is simply not enough to create a framework which provides only this view of the problem domain. The information that is provided by traditional task analyses is also important in so far as it represents one aspect of the relationship that will exist between the pilot and the Pilot's Associate.

The inadequacies of traditional language based knowledge acquisition methods has prompted the inclusion of three techniques that provide the domain expert with the media necessary to: 1) achieve uninformed access to the pilot's perspective on the requirements of the mission, 2) acquire access to the analyst's perspective on the mission requirements, and 3) elicit the tacit knowledge and perceptual learning that has been acquired through experience with the problem domain. Figure 1-2 presents an overview of the approach taken to apply the advanced user requirement and design framework to the PA/Pilot-Vehicle Interface problems previously identified.

A more complete and efficacious framework will emerge if the potential exists to: 1) capture a pilot's perception of his mission; 2) capture an analyst's view of the mission; 3) integrate both these perspectives with the designer's view of the mission; and 4) provide an environment where collaborative analysis, synthesis, and design may be assimilated and generated in exponential fashion. Each of these perspectives: the pilot's, the analyst's, and the designer's is elicited using a different procedure. Each of these procedures elicits a <u>different type</u> of knowledge, and employs a different method for representing that knowledge. The primary objective of this research project is the development of a methodology that is capable of first eliciting the knowledge associated with each of these perspectives, then explicitly representing these different knowledge types using different representational techniques, and finally proposing a 'transformational grammar' which would allow for the establishment of interconnections among these different knowledge representations. This knowledge and design acquisition methodology is intended to: 1) highlight common concept elements for analysis; 2) identify information requirements; 3) prototype and evolve design storyboards; and 4) document the rationale behind any requirement or design.

The pilot's perspective of the mission and his or her experiential knowledge is captured by the interactive knowledge elicitation and representation technique termed <u>Concept Mapping</u> (McFarren, 1987). The emphasis within this experiential knowledge representation is upon the identification of requirements and the associated specific knowledge useful in satisfying these requirements. The form of a pilot's comprehension of a mission may be declarative, using a concept definition map, or procedural, using a time-line concept map. In either form, the knowledge elicitation is derived from episodes or experience which each pilot can access. Within

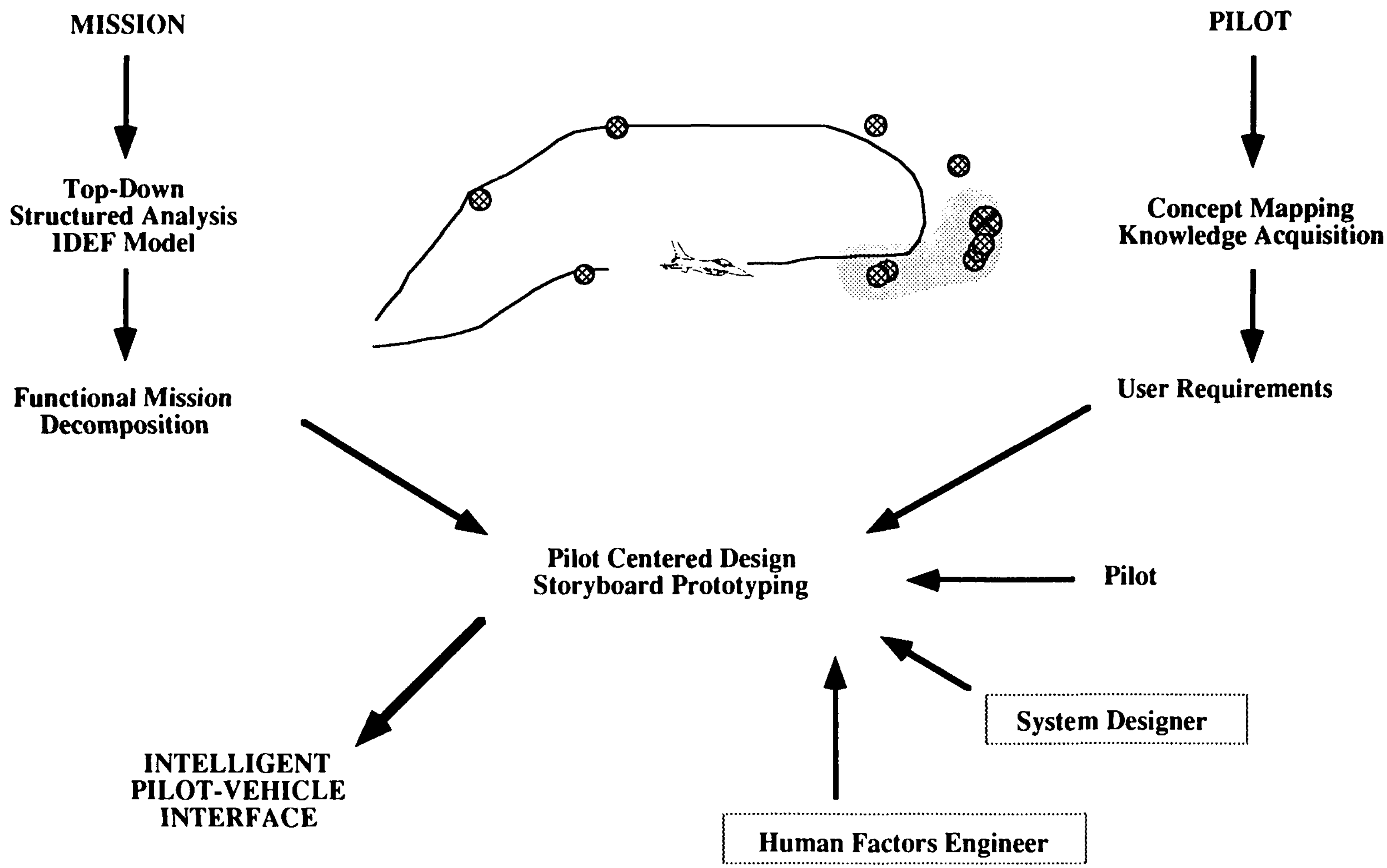


Figure 1-2 Overview of the Knowledge and Design Acquisition Methodology

either form, the pilot's information requirements, decision-action points, and key concepts are represented.

The concept mapping technique offers the opportunity to access two interrelated processes pertaining to the pilot's conceptualization of the mission. The technique offers the opportunity to acquire the '**information heeded**' and '**information remembered**' depending upon the level of intrusion (i.e., probing) that occurs during the elicitation process. The information heeded is elicited as the pilot is allowed to "think aloud" wherein there is minimal amount of intrusion by the interviewer. The information remembered results when the interviewer intervenes to direct the pilot's memory along a selected path.

The analytical view of the mission elicits a structural knowledge in the form of a top-down, normative, functional mission decomposition. This knowledge is captured using a structural analysis tool referred to as either the Structured Analysis and Design Technique, (SADT), or the Integrated Computer Aided Manufacturing Definition (IDEF). The emphasis within the structural knowledge representation is the relationship among input, process, control, resources, and output which take the forms of mission procedures (i.e., sequences of tasks), tasks (<u>prescribed</u> <u>actions</u> to take), and decisions (selection of courses of action). The question which the structural knowledge element of the overall framework purports to answer is: "What is a pilot supposed to do in a given point in the mission?" (i.e., planning, monitoring system status, performing control action, etc.). This analytical knowledge may be doctrinal or functional in nature, but engulfs the process of '**information told**' as formed while analyzing a mission context.

The design view of the mission elicits '**Knowledge as Design**' (see Perkins, 1986 for more specific elaboration on this topic) usually in the form of visual, tactile, or auditory objects, perceivable as prototypes of real world referents. Hence, there is a transformation of semantic-based knowledge into perceptual-object based (i.e., isomorphic) representations upon which designers tend to focus. Knowledge and <u>design</u> acquisition can now involve the noticing of perceptual features which is the basis for problem solving, discovery, and learning (Bransford, Sherwood, Vye, and Rieser, 1986). Design objects are prototyped with design storyboarding tools (Andriole, 1988) using the <u>Supercard</u> application software (Silicon Beach Software, 1990). The emphasis within the knowledge as design model is the use of specific frames which unwind over time to provide a perceptual understanding of information requirements, for a targeted event or mission segment. The design storyboarding process first involves **information fused** as it allows a pervasive sweep over the other processes involving information heeded, information remembered, and information told; to synthesize a specific design. It provides the knowledge engineer with a means of answering the question: "How would I create a design given these requirements?" Once a design is formulated it gives rise to a second process, **information perceived**, which affords the opportunity for other design team members to assess and evaluate the design creation. The question that the design storyboard can answer is: "What do I perceive from, and how should I interact with, the given design?" When information can be 'perceived' and 'fused' iteratively, new information requirements may be learned and new facets of design may be uncovered and generated. As 'designers' begin to recognize changes in their own perceptions of a problem, learning and discovery unfold. Design may simultaneously be recurrent, concurrent, and doctrinal.

The knowledge and design acquisition methodology that will be described in the following sections provides three different representations of the target acquisition phase of a tactical air-to-ground mission. The process described in the following sections is intended to provide a methodology capable of eliciting a broad-based understanding of the pilot interaction with current and future systems. The knowledge and design acquisition methodology begins to dissipate the traditional knowledge acquisition bottleneck by providing a medium that permits the establishment of shared understanding between the knowledge engineer and the domain expert which is both verbal and perceptual in nature.

2 CONCEPT MAPPING: A PILOT'S VIEW OF THE MISSION

2.0 History of Concept Mapping

In order to develop a theoretical perspective from which the concept mapping technique can be considered, a brief history of its origins will be provided.

2.0.1 Semantic Networks

The origins of concept mapping can be traced back to Quillian's (1968) seminal work on semantic networks. The semantic network model was originally proposed as a representation of human information processing that could explain some of the numerous effects that meaning has on memory. It was intended as an explanation to phenomena such as the "category-size effect" in which it was found that category classification takes longer when the item is a member of a large category class than when it is a member of a smaller class. Quillian's model was exceptionally simple, consisting of points (referred to as *nodes*) that represented concepts, and the arcs between the points representing the relationship between the concepts. The meaning of any particular concept within the semantic network was represented by the connections (or *associations*) with other concepts within that network. The meaning of any word within a semantic network was expressed by its relationships to other words resulting in what has been referred to as concept's *associative structure*.

Collins and Quillian's (1969) research on the psychological validity of the semantic network model attempted to show that the human memory obeys the same organizational principles that are exhibited by the model. Specifically, they claimed that the human memory obeys the organizational principles of hierarchy and economy. The first organizational principle, that of hierarchy, asserts that semantic memory is organized in a hierarchical fashion. The validation efforts used reaction time measures in an attempt to demonstrate that the time required to confirm a given proposition's validity varied as a function of the number of inferential steps between the concepts included within the proposition. The number of inferential steps was thought to increase as the distance between the concepts in the hierarchical structure increased. For instance, Collins and

Quillian predicted that it would take an individual longer to confirm a proposition like *A canary is an animal* than it would to confirm a proposition like *A canary is a bird* because of the increased number of inferential steps through the hierarchy to confirm the former proposition (see Figure 2-1). The data from the Collins and Quillian study, as well as the data from similar studies (Conrad, 1972) confirm this prediction.

The second organizational principle, the principle of economy, asserts that a property common to a superset concept also applies to those nodes which lie beneath it in the hierarchy. There is economy produced when the attributes are stored at high levels and not stored for each subordinate concept. Leahey & Harris (1985, p 132), for example, indicated that information such as "has feathers" and "is two-legged" is stored at the superordinate node "bird" and thus need not be stored at each nodes subordinate to "bird". Collins and Quillian (1969) data support the claims of the economy principle; however, they must be regarded as inconclusive, in so far as other studies (Conrad, 1972; Smith, Shoben, & Rips,1974) have been able to generate alternative hypotheses that are consistent with the observed data.

Although the empirical tests of Quillian's (1968) model of semantic memory have not proven entirely conclusive as a general model of human memory, Quillian's work on semantic networks continues to receive considerable attention. Later models of human semantic memory (Anderson, 1976, 1980, 1989; Anderson & Bower, 1973; Hinton, James, & Anderson, 1989; Kintsch, 1977; Lindsay & Norman, 1977; Minsky, 1986; Rumelhart, Lindsay, & Norman, 1972; Shank, 1984; Sowa, 1984) while showing increasing complexity, tend to incorporate as the underlying structure a semantic network. There are significant differences between these various accounts of human semantic memory, but there does appear to be a considerable degree of agreement regarding the underlying structure and organization of semantic memory, a structure which still bears a close resemblance to Quillian's semantic network. The basic premise which is common to all of these accounts is that knowledge is represented by concepts, and that the acquisition of additional knowledge (i.e., learning) is based upon the ability to take the basic concepts already possessed, and combine them as needed to represent any additional

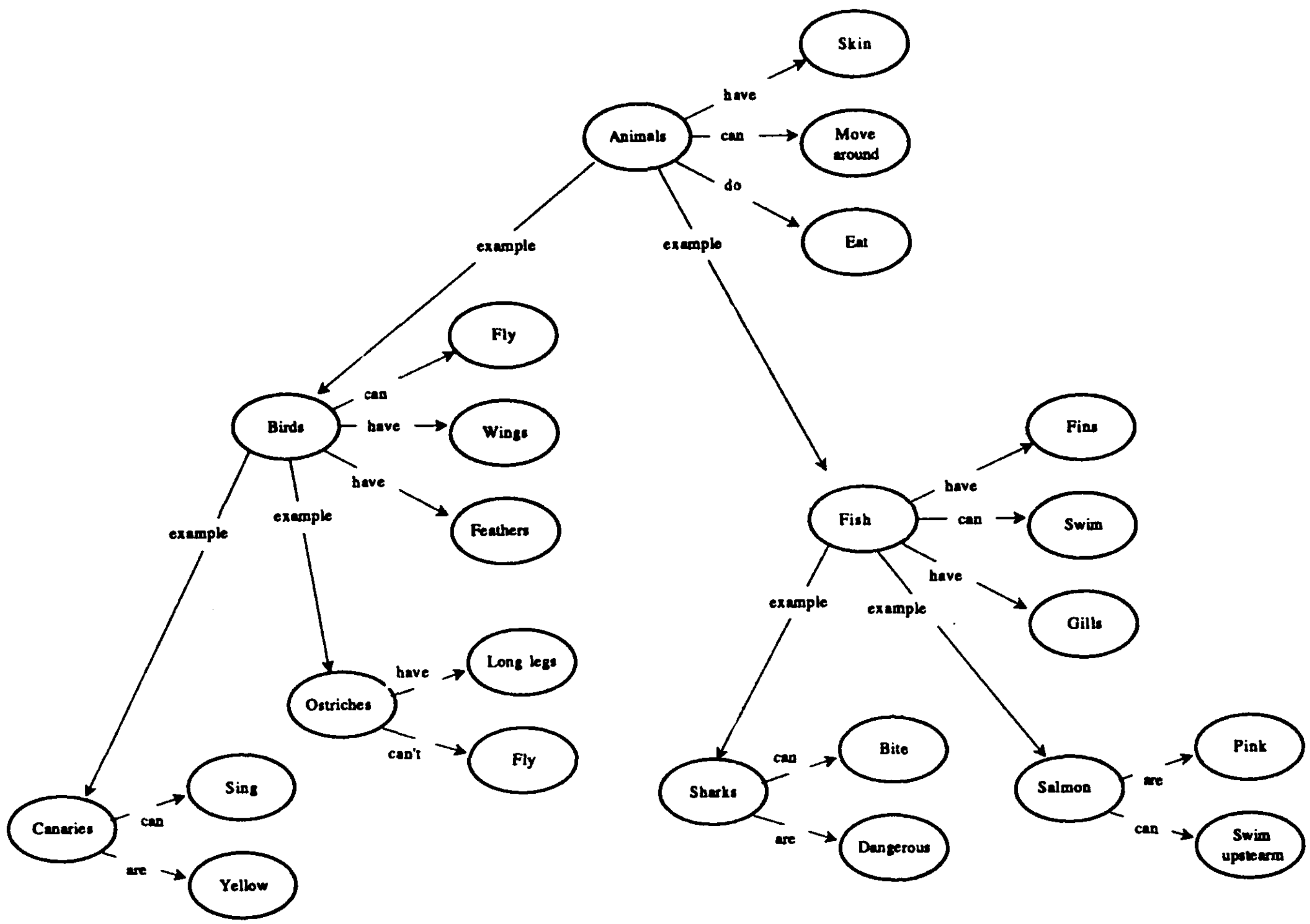


Figure 2-1 A Hierarchical Memory Structure

information to be added to the network. Shank (1984) suggests that our ability to understand information is a consequence of being able to relate it to what we already know. The more we know about the world and the more experiences we have had, the better equipped we are to find possible meanings for new information. Additionally, the more we know, the better we comprehend and remember new knowledge which can be integrated within prior themes (Morris, Stein, & Bransford, 1979). Similarly, current theories of learning suggest that knowledge construction and elaboration occur through the assimilation of key ideas from a complex collection of sources into an interlinked, meaningful mental model (Spiro, 1977).

Advances in semantic network models have currently taken the forms of schemata, scripts, and neural networks. Consequently, this has broadened the issues of their applicability beyond just memory representation to now include the use of memory in comprehension, meaning, and learning.

2.1 Concept Mapping as a Teaching Technique

Developing shared knowledge is one of the major objectives of the education process. Research on learning supports this idea by demonstrating that students' performance improves as the array of associations among the set of concepts possessed by the students begins to more closely approximate the array of associations possessed by the domain experts (Brown, Collins, & Duguid, 1989). With this understanding in mind, it is widely believed that the structure and organization of human associative memory can be adequately represented using semantic network models. Several education theorists (Novak & Gowin, 1984; Fisher, Faletti, & Quinn, 1990) adopted the technique for graphically representing information that is to be transferred from one individual to another (see above Figure 2-1). This method provides a more effective way of transferring information from one individual to another by overcoming many of the limitations inherent in the linear presentation of material. The effectiveness of a method that is based on Quillian's semantic network model is derived from the fact that the information is being presented in a form that more closely matches the cognitive structure of the individual acquiring the information (Novak & Gowin, 1984; Nosek & Roth, 1990). In its original inception this representation technique is referred to by Novak and Gowin (1984) as concept mapping.

Concept mapping was designed as a method that would be consistent with the learner's cognitive structure and which would externalize for both the learner and the teacher 'what the learner already knows.' A concept map consists of two or more concepts that are linked to each other, thereby depicting a meaningful relationship that exists between the represented concepts. The concepts within this concept map are units of information such as objects, phrases, images, sounds, ideas, and events which are assigned a semantic label. Each concept is understood through its relations to other concepts. The relations are a special set of associations that serve to describe how these concepts are connected to one another. Relations are linking words which are most often verbs or prepositions; however, any word that is capable of expressing the relationship between two concepts in a meaningful fashion can function as a relation. The network of relations gives meaning to a concept. When a concept map has been produced, the result is a schematic device that represents a set of concept meanings embedded in a framework of propositions (Novak & Gowin, 1984).

2.2 Distinctions between Semantic Networks and Concept Maps

Although concept maps are theoretically related to semantic networks, and although the two terms are often treated as being synonymous, it is useful to point out some of the distinguishing features between the two types of representations.[5] One of the principle distinguishing features between concept maps and semantic networks is that concept maps are constructed heterarchically with many links emerging between the concepts, and with

[5] We would expand codification for the Pilot's Associate program to also include design of the pilot-vehicle interface wherein concept maps would be used to code human factor engineering designs.

subordinate concepts in the array being linked to superordinate concepts.[6] Semantic network models (e.g., Quillian, 1968) in contrast are organized in a principally hierarchical fashion with relatively few links between the concepts. In this sense, concept maps may be more closely aligned with connectionist models of human memory (Rumelhart & McClelland, 1986) rather than the earlier semantic network models.

Another important distinction between semantic network models and concept maps is that the semantic network models are typically intended to reflect the organizational structure inherent to human semantic memory in general, instead of reflecting only the knowledge and experiences of the individual whose knowledge is being graphically represented. The heterarchical structure which emerges in the concept map is principally a function of the individual whose knowledge is leading to the construction of the concept map. As such, the meaning embedded within a concept map is a product of an individual's knowledge and experience with the subject matter. Because of this fact, any individual's concept map is necessarily subject to variations over time as additional knowledge is incorporated into an existing map, and as the context against which the information represented within the concept map changes. Such changes may be the result of assimilating more knowledge over time (for both domain expert and knowledge engineer) as well as recognition by the domain expert that he or she forgot to include relevant information during a prior session. Rather than being indicative of how the human mind is organized in general, or being representative of the static structure of that organization, a concept map is a snapshot of a dynamic process. The snapshot represents the way the individual is currently thinking about the concepts within a given domain, given a particular context.

As the context from which an individual conceives of the concepts changes, the concept map may undergo a rearrangement wherein a subordinate concept assumes a superordinate position, causing the subsequent rearrangement of the relationship between the concepts. This phenomenon has been referred to as the "Rubber Sheet" effect (see Figure 2-2), and is assumed to reflect the same changes that occur within an

[6] It should be reiterated here that information requirements shown on this summary map are not inclusive, but merely examples and provide an identification of areas rich for further investigation.

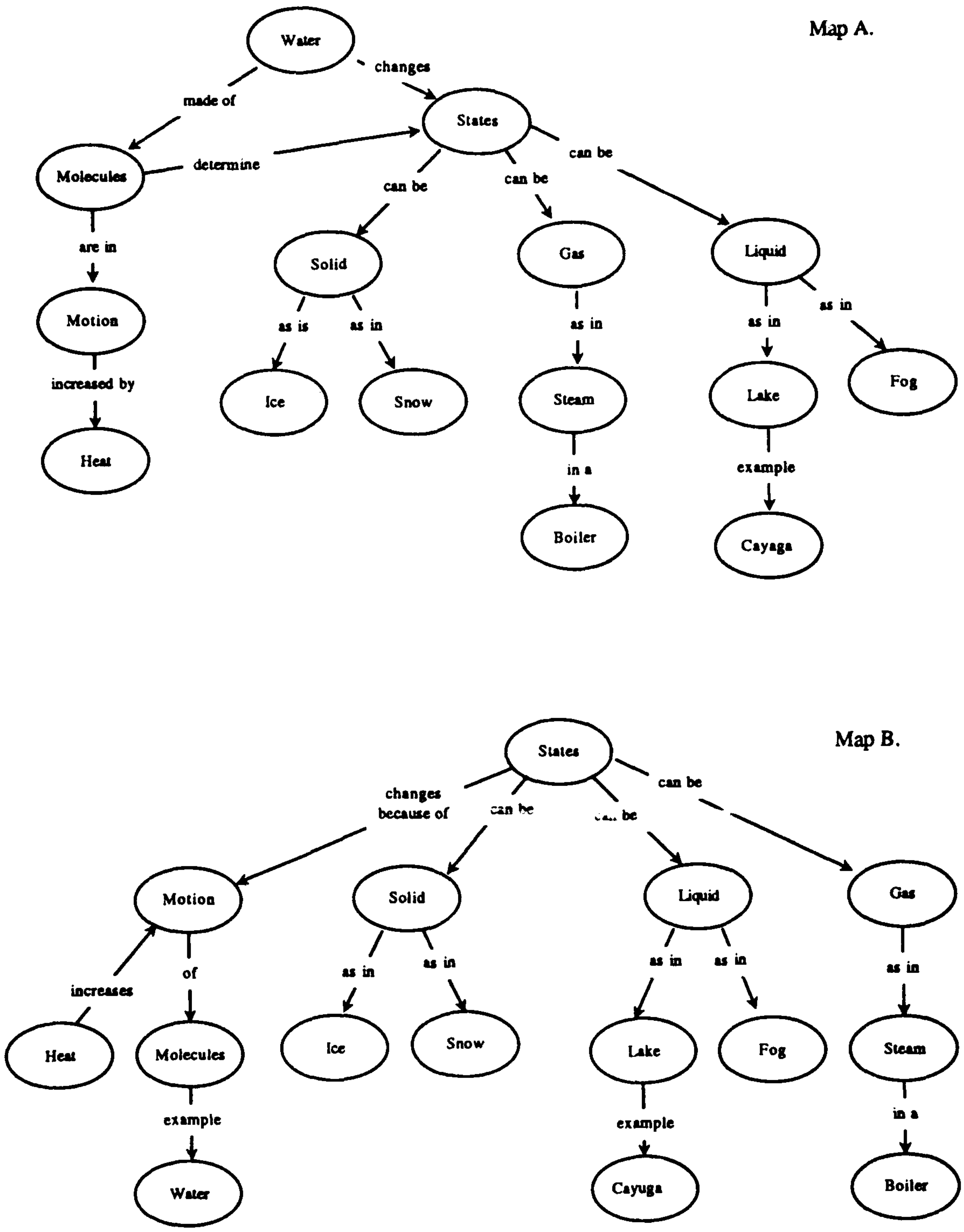


Figure 2-2 A Concept Map for States Showing the "Rubber Sheet" (adapted from McFarren, 1987)

individual's mind as he or she views a given subject matter from a different perspective or from amidst a different context (Novak & Gowin, 1984). The same concepts are portrayed in each of the concept maps in Figure 2-2, but the organization has been changed to reveal alternate meanings and a new emphasis within the domain. This also brings up the point that whenever an observer views a concept map, it is from that person's personal frame of reference which is not necessarily or likely to be the same as the domain expert's. Consequently, different people see different things in concept maps as they 'mentally' invoke the rubber sheet effect. This allows information requirements to be spawned from a variety of different emphases. The network of relations which gives meaning to the concepts is highly context dependent, and the alternate meaning shown in the two maps is depicted through the change in the links that exist between the concepts.

2.3 Prior Success of Concept Mapping

The concept mapping technique has been used to capture the knowledge structure of the learner in order to facilitate the transfer of information from the teacher to the learner. With the representation of the student's knowledge made explicit, it becomes easier for a teacher to indicate to the student the relationship that should exist between the new concepts, and the concepts that are already possessed by the student (Armbruster & Anderson, 1984; Novak, Gowin & Johansen, 1983; Novak & Gowin, 1984). The technique has also been used as a method for evaluating the extent of the student's knowledge (Fisher, Faletti, & Quinn, 1990; Naveh-Benjamin et. al., 1986), and it has been used successfully by teachers to convey information to students. Expert-produced maps have been substituted for traditional text in order to convey complex ideas to students with positive results (Hall, Dansereau, & Skaggs, 1988; cited in Lambiotte et. al., 1989).

Concept mapping has proven to be a useful technique for: 1) transferring information from one individual to another; 2) for identifying the key ideas within a given subject; 3) for providing a formalism that is closely analogous to the mental organization of the individual being mapped; and 4) summarizing a given cognitive domain (McFarren, 1987; Novak & Gowin, 1984). Concept mapping, according to Fisher, Faletti, and Quinn "lets one person 'see what another is thinking' at a level of detail heretofore unattainable." They go on to say that "this formalism is (if semantic networking theory is correct) more analogous to mental representations than are most linguistic structures, (p. 4, 1990)" and thus, provides the researcher and educator alike, with a unique window into the mind of the individual that is being mapped. Concept maps allow one person to see how others abstract their knowledge, the concepts that they choose to represent, and the ways in which they choose to link the concepts together.

2.4 Concept Mapping as a Knowledge Acquisition Tool

Translating the concept mapping technique from a tool that facilitates the transfer of information from one individual to another in an educational setting, to a tool that performs similar functions for the development of a decision support system, occurs easily and without significant modification (McFarren, 1987). When used as a knowledge acquisition tool, the domain expert assumes the role of the teacher, and the knowledge engineer, the role of the learner. The concept map that is generated constitutes a snapshot representing the cognitive structure of the domain expert and can be used to transfer this information to the knowledge engineer and to the designer of the decision support system. The information that the knowledge engineer now has about the expert's understanding of the problem domain can be used to identify the user's requirement for a decision support system that is intended to aid in the performance activities within this specified domain.

The same characteristics of concept mapping that make it an effective method for transferring information in an educational setting make it an effective technique for transferring information in the field of knowledge acquisition. If the various theories regarding the structure and organization of human semantic memory are correct, including some of the current theories (e.g. Anderson,1980, 1989; Hinton, James, & Anderson, 1989 Minsky, 1986; Shank, 1984; Sowa, 1984), then the concept mapping technique offers the knowledge engineer a tool that more closely matches the characteristic of human semantic memory than other available knowledge acquisition tools. It affords a way of escaping the restrictiveness of the linear thought process that is reflected in both written and spoken language (Lambiotte, et. al., 1989). Concept mapping thereby allows for the expression of the domain expert's knowledge without requiring that it be translated into a form that is acceptable for typical communications.

When decision support systems utilize an AI architecture and knowledge representation which is also derived from semantic networks (e.g. scripts) than there is a direct transmittal and relationship between human memory, the acquisition of this memory, and the consequent representation of this memory in an AI architecture. This then becomes a sound basis to form AI models which can be highly integrated with their operators (see McNeese, 1986).

2.5 Concept Mapping Power

Concept mapping is an interactive interview technique which provides both the expert and the knowledge engineer a medium within which to communicate, and a means of knowing what information was communicated. The more traditional interview techniques do not readily allow the expert to know what the interviewer has grasped, nor whether it has been misinterpreted. With concept mapping, however, the expert can see, represented on the board before him or her, what the knowledge engineer has understood or what the knowledge engineer has misinterpreted. This unique feature of the concept mapping technique also allows the domain expert to quickly correct any misrepresentations of his or her understanding long before they find themselves implemented as software or hardware designs.

In addition to capturing the domain expert's knowledge and his or her understanding of the problem domain, the concept mapping technique can actually aid the expert in organizing the presentation of his or her knowledge. Because the expert is rarely, if ever, asked to make a formal presentation of his or her knowledge domain in the context of a knowledge acquisition session, the concept map provides the expert with a way of organizing his or her thoughts. The expert can freely associate, following a particular train of thought, and return easily to the original idea without losing his or her place because the concept map serves as an external memory aid that shows the expert where he or she has been, and what the interviewer has understood. The concept mapping technique can then be used by the domain expert to assist the knowledge engineer and system designer in understanding the nuances of a knowledge domain and help in the identification of areas that pose performance problems for the domain expert.

Concept mapping is regarded as a flexibly non-obtrusive knowledge acquisition technique. The non-obtrusiveness of the concept mapping technique refers to the fact that the technique itself does not interfere with the domain expert's conceptualization of the problem domain. The technique facilitates a consistency between the expert's understanding of the domain and the way in which that information is represented. The idea of flexibility refers to the fact that the interviewer can probe for additional information during the interview. The flexibly non-obtrusive quality allows the knowledge engineer to vary the degree to which he or she directs the course of the mapping session. This quality also affords the opportunity to utilize the advantages of the concept mapping technique's graphic and interactive attributes with other strategies for eliciting knowledge from a domain expert. For instance, the concept mapping technique can be used as the structure within which the Critical Decision Method is employed (Klein, Calderwood, & Clinton-Cirocco, 1986; Calderwood, Crandall, & Klein, 1987; Klein, Calderwood & MacGregor, 1989).

The concept mapping technique facilitates the identification of key ideas within a subject area through the use of its graphical representation techniques. According to Lambiotte et. al., (1989) "the map's spatial properties allow the individual to immediately identify characteristics of the knowledge domain such as overall complexity, differential complexity of subareas of the map, areas of symmetry and gaps in the domain expressed by breaks in symmetry, continuation, or closure" (p. 359). This automatic recognition of the domain characteristics can guide the map reader during the extraction of detailed meaning, thereby facilitating the identification of key ideas within the particular knowledge domain. The graphical representations employed by the concept mapping technique allow for easy comprehension and definition of complex problem spaces. The network of concepts that are portrayed by the concept map enables a reader of the map to conceptualize highly complex interrelationships that threaten to exceed human cognitive limitations.

It has long been known that humans possess inherent cognitive limitations which constrain the individual to actively attend to no more than approximately seven units of information (Miller, 1956). Although it cannot be said that a concept map permits an individual to exceed this limit, it does have the characteristics which enable an individual to work more effectively within the limitations that do exist. The graphic characteristic of the concept map will allow the reader to use an external memory aid in order to grasp complex interactions among concepts that could otherwise potentially exceed his or her cognitive capacity. The concept map also allows readers the opportunity to 'chunk' together concept clusters to effectively expand the size of units; thereby, increasing the range of their cognitive capacity.

2.6 Practical Issues Affecting Knowledge Acquisition

In addition to being well grounded in theory, it is important that knowledge acquisition techniques also satisfy several practical concerns in order for the method to actually be effective at eliciting knowledge from a domain expert. As Klein, Calderwood, and MacGregor (1989) point out, any method that is to be at all useful must first satisfy certain basic requirements with regard to practicality.

First, the method must be time efficient, as it is unusual to be able to secure more than a two-hour interview session with any given domain expert. Even if greater amounts of time were available, the amount of information that can be elicited from an individual begins to rapidly wane as fatigue sets in. Thus, the knowledge acquisition technique must make efficient use of the time that is available, and be flexible enough to allow for the integration of several short knowledge acquisition sessions. Concept mapping makes efficient use of the domain expert's time by facilitating the rapid transfer of domain knowledge and enabling the knowledge elicitor to prepare and prioritize probes that can direct the expert's presentation of information. The graphic presentation method that is employed with the concept mapping technique makes the technique particularly well suited for use during extremely short knowledge acquisition sessions. The domain expert will be able to quickly identify where he or she has stopped during the previous session, thereby highlighting its ability to establish consistency and continuance across sessions.

Second, the method must provide a cost effective means for data collection and analysis. With budget restrictions, it is important that the collection of domain knowledge not be cost prohibitive. Collecting and analyzing a speak-aloud protocol generated by running the domain expert through a veridical simulation of the domain environment, may provide a rich source of information. Unfortunately, the costs associated with such procedures are significant. Also, the depth and breadth of the knowledge acquired may not be better than those of knowledge gleaned using the knowledge and design acquisition techniques that are being described in this report. In contrast to a full scale simulation and all of its associated costs, the concept mapping technique requires nothing more than a writing surface (chalk board, dry-marker board, paper, etc.) and a tape recorder.

Third, the knowledge acquisition method must be capable of representing the knowledge that has been gleaned from the knowledge acquisition session in a form that facilitates its codification in a decision support system (Klein, 1990). This process frequently involves a translation of the information derived from the knowledge acquisition sessions into a form that allows for easy communication between the parties involved in the process of design and constructing decision support systems. The translation can be a time consuming and difficult process, and perhaps more significantly, it can involve the loss or misinterpretation of information as it is changed from one representational medium into another. The concept mapping technique provides a distinct advantage in so far as the domain expert's knowledge is captured during the knowledge acquisition session in a form that can be directly embodied in a decision support/AI system (e.g., Bareiss, 1989; Carbonell, 1970; Buchanon & Shortliffe,1984; Duda, Hart, Barrett, Gaschnig, Konolige, Reboh, & Slocum, 1978; Duda, Hart, Nilsson, & Sutherland, 1978; Lebowitz, 1986; Nirenburg, Monarch, Kaufmann, Nirenburg, & Carbonell, 1988; Routh, Milne, & Kabrisky, 1986). The representation of expert knowledge in a semantic network is useful because it facilitates "making deductions about inheritance hierarchies, and . . . enables more direct and controlled search rather than a search through the whole data base" (Nosek & Roth, 1990).

Nosek and Roth (1990) recently conducted a study in which they compared what they regarded as the two most popular knowledge representation techniques currently being used in the AI field, semantic networks and predicate logic. Nosek and Roth's work indicates that a semantic network scheme is a transparent method for representing the expert's knowledge in the sense that its structure does not interfere with an individual's ability to comprehend the information that is being represented. Specifically, the results of their study reveal that the semantic network scheme as a knowledge representation technique was superior to predicate logic in the areas of problem identification, comprehension, generalization and application. However, while Nosek and Roth recognize the usefulness of semantic network-like representations in facilitating the communication of information between the knowledge engineer and the domain expert, they conceive of it as primarily a method for validating the transfer of information without considering its potential utility as a method for eliciting the information. According to Nosek and Roth:

> "The knowledge of the expert is transferred to the knowledge engineer through the communication channels of oral and written descriptions and through observation. To obtain the expert's validation of the transfer process from the expert to the knowledge engineer, the knowledge engineer transfers the knowledge content to the expert via a representation scheme. The representation scheme then becomes the major communication vehicle" (p. 228, 1990).

We are suggesting that the utility of representation schemes can be greatly enhanced if the method is also used as the medium for transferring the knowledge of the expert to the knowledge engineer (in the form of the concept mapping technique) instead of only serving as a technique for validating the original communication which has been accomplished using other knowledge acquisition techniques.

The fourth practical issue affecting the selection of knowledge acquisition methods involves the level of training needed by the knowledge engineer. The nature of the concept mapping technique is such that it requires a minimal amount of prior domain knowledge in order for the knowledge engineer to effectively use the method. In addition, the technique itself is easy to master (for both the knowledge engineer and the domain expert) thereby avoiding lengthy training sessions.

2.7 Concept Mapping Basics: Methodology, Syntax and Structure

The use of concept mapping as a knowledge acquisition tool involves interactively producing a concept map of the domain expert's knowledge during an interview with that expert. The concept map, in fact, becomes the vehicle for transferring knowledge from the domain expert to the knowledge engineer as the domain expert leads the knowledge engineer on a conceptual journey through the subject material. Unlike other interview techniques, whether structured or unstructured, the concept mapping technique enables the domain expert to literally see what, and how the knowledge engineer has interpreted the information that he or she has presented. A frequent complaint issued by domain experts concerning the use of interviews for knowledge acquisition, is that the knowledge engineer 'hears and remembers only what is consistent with his or her prior conception' and not what the domain expert actually intended. Regardless of the reasons resulting in this misrepresentation of information, the interactive nature of the concept mapping technique enables the domain expert to review and correct misrepresentations as they occur (as well as at a later date after the maps have been cleaned up by the knowledge engineer). Hence, the domain expert is involved in both on-line and off-line review of the map.

In order to ensure that the concept mapping session remains interactive, it is necessary that the map be legible to both knowledge engineer and domain expert. The map that is produced during the session closely resembles the map shown above in Figure 2-1. The form, structure, and syntax of the concept maps used for the purposes of knowledge acquisition are kept extremely simple in order to ensure that the representation is transparent to a reader (McFarren, 1987). The graphic representation consists minimally of a pair of concepts, which are assigned a semantic label and linked to one another by the relationship existing between the two concepts. (see Figure 2-3). As the complexity of a given problem domain increases, additional relations and concepts are added to the map without requiring an increase in the complexity of the syntax that is used to govern the structure of the map.

Throughout concept mapping's history of usage in both educational and computer science settings, there has been a tendency to increase the number of rules governing the construction of concept maps in the belief that this increased specificity will lead to greater precision (Lambiotte et. al., 1989). For instance, efforts have been made to define a canonical set of relations that could be used to parsimoniously represent the knowledge in a given domain (Holley & Dansereau, 1984; Fisher, et. al., 1990). Lambiotte, et. al. describe a wide array of graphical conventions that they have adopted in the belief that such techniques will foster the efficient communication of information about concepts and the multiple relationships among the concepts. While these efforts may in fact promote parsimony with respect to the analysis of the concept map, they were viewed as counter-productive in the context of the goals of a knowledge acquisition technique. Our use of the concept mapping technique has led us to believe that several of the technique's principle advantages as a knowledge acquisition tool (i.e., its use in maintaining an interactive interview, and its transparency to the reader) would be compromised if these various additional rules were actually incorporated. The one rule that should be followed is to insure that all the relations and concepts are labeled, for it has been found that maps that have been produced without labeled arcs are difficult to comprehend (Lambiotte, et. al., 1989).

Nodes = Concepts { **Object, Actions, Events**

Arrows = Relationships

Figure 2-3 Concept Mapping Syntax

2.8 Concept Mapping of a Tactical Air-To-Ground Mission

This section describes the applications of the concept mapping technique to the problem of eliciting domain knowledge from experienced tactical fighter pilots for the purposes of identifying and validating a detailed set of user requirements. This methodology allows for not only the identification of user requirements, but also facilitates the communication of user requirements to the designers of the Pilot's Associate. It should be noted, however, that the present effort is intended to be a demonstration that these methods, if applied in a full scale effort, would be a highly effective means of capturing the user's understanding of the problem domain. Thus, the results presented should not be considered definitive, but rather indicative of the type of information that this technique is capable of generating. In order to facilitate this investigation, the concept mapping sessions focused only on the target acquisition phase of the tactical fighter mission, and were directed toward uncovering the pilot's information requirements for a pilot-vehicle interface.

2.9 Methodology

The interview sessions were conducted using an interview panel format with one domain expert, and two-to-five interviewers assisting with the interview. A single interviewer served as the concept mapper during all of the interview sessions. The other interviewers participating in the session were tasked with generating the questions and probes in order to gain more detailed information about the concepts that were being presented by the domain expert.

Eight domain experts were interviewed during the concept demonstration phase of this project. Six of these were tactical fighter pilots with an average of 2300 hours of logged flight time (ranging between 700 and 5000 hours) in F-4s, and F-16s, and extensive experience flying tactical air-to-ground missions. Of the remaining two domain experts, one was a

F-4 backseater and pilot instructor, and the other was a B-52 pilot with extensive tactical air-to-ground experience.

Each domain expert was interviewed for an average of two hours on two separate occasions, with the focus of the session differing on each occasion. The first round interviews were intended to elicit general knowledge of the domain that was independent of a specific aircraft, mission, target, or weapon type. This session was divided into two parts of approximately equal length. The first half of the interview concentrated on the definition of target acquisition during a tactical air-to-ground mission, and the second half focused on the specific procedures and decisions that the pilot would make during that particular phase of the mission. The second round interviews were similarly divided into two parts, with the first half focusing on the validation and clarification of the map(s) produced during the first session interview. During the second half of the second interview session, the pilots were given a specific mission profile consisting of a specified target, weapon type and attack geometry in order to establish the context for the interview. With this context as a backdrop, the pilots were probed for additional detailed knowledge regarding the key decision points encountered during the target acquisition phase of the mission, and the information used to make the decisions.

The first session interview began with a brief introduction to the concept mapping technique. Because this knowledge elicitation technique is an interactive one, it was important that the domain expert (i.e., the pilot) had at least a rough understanding of what the technique was, and what he was expected to contribute. It was explained to the pilot that the technique that was being used was designed to capture his understanding, and that we were primarily concerned with his conceptualization of the problem domain (i.e., tactical air-to-ground mission). In order to insure that the knowledge depicted in the concept map actually represented the pilot's understanding of the problem domain, the pilot was strongly encouraged to correct, edit, or re-draw the map that was being produced. The pilot was also informed at this time that an audio recording of the session would be produced.

The context for this knowledge acquisition session was set by informing the domain expert of the specific portion of the problem domain of interest. Specifically, the pilots were informed of our interest in the target acquisition phase of an air-to-ground mission. The pilots were asked to describe the procedures and decisions involved, and we stressed the fact that we were particularly interested in the information that they use to make each decision and how this information should be displayed. The pilots were also asked to describe the various concerns that they have during each segment of the target acquisition phase of the mission. During the first interview session, few constraints were imposed upon the focus of the discussion, beyond limiting it to the target acquisition phase of tactical air-to-ground mission. In other words, the pilot's were not asked to limit their discussion to a specific aircraft, mission, target, or weapon type. The rationale for avoiding the imposition of excessive constraints was to allow a wide exposure of the issues during the initial round of interviews.

Throughout the mapping session, the pilot's conceptualization of the target acquisition phase of the mission was captured in the concept map. As the pilot presented information, a concept map was drawn on a white, dry-marker board in front of him so that both he and interviewers could easily see and discuss the concepts that were being represented. Typically, the map was drawn by one of the interviewers as the pilot spoke, although on several occasions the pilots have themselves participated in the drawing of their own concept map. The fact that the map was drawn in front of the domain expert so that he could read the map as it emerged is a particularly important aspect of the interview process, and the pilots were encouraged to interact with the maps by reading, editing and correcting them throughout both portions of the concept mapping session.

At appropriate times throughout the mapping session, the pilot was probed with questions (both planned and impromptu) which asked for clarification or additional information on concepts that were being discussed (see Table 2-1). A conscientious effort was made not to interrupt the pilot's train of thought, but to ask the question only when additional information was sought regarding a particular concept, or when there was a lull in the discussion. Thus, in practice, the majority of the questions were raised after the pilot had concluded his presentation of his understanding of the target acquisition phase of a tactical air-to-ground mission. Because the concept map provides a clear graphical

TABLE 2-1.

Potential Probes For Concept Mapping Session

1) Define and elaborate upon concepts associated with:

Attack
Weapon Release
Changes in Target Location
Attack Plan Deviation
Target Misidentification
G-Limit/Heavyweight Maneuvering

2) How is target acquisition effected by:

Weapon Type
Target Type
Weather
Terrain/Obstacles Obscuring Target
Pop-up Threats
Equipment Malfunctions

3) What do you look for when you are trying to find the target area, and target just prior to weapons release?

4) What is the most difficult aspect of target acquistion during an air-to-ground mission?

5) When describing the steps involved in target acquisition you mention transitioning from one step or sequence to another, what information do you use when deciding to move on to the next step?

6) What is the source of the information that you use when making the decision? How is that information displayed? How would you like to see it displayed?

7) What information would have aided the decision, making it more timely, more accurate, less demanding or less uncertain?

8) What are your goals during this particular phase of the mission?

9) What are your principle concerns during this particular phase of the mission?

representation of the pilot's knowledge, the questions could be asked in such a way that they referred back to a particular portion of the concept map thereby allowing for the integration of the additional information with the existing map.

During the second phase of the first round interview, when the specific procedures and decisions that the pilot makes during the target acquisition phase were being discussed, an event time-line was provided to facilitate the mapping of sequential processes as well as the pilot's thoughts concerning those processes. The time-line also afforded a means to represent the specific context against which a particular sequence of activities would be cast (see Figure 2-4).

After the completion of the second phase of this interview, the pilot was given the opportunity to review the map that had been generated. Even though the pilot had been interacting with the map throughout the course of its generation, he was given an additional opportunity to correct any misrepresentations and to fill-in any omitted information.

The second session interviews began with a review of the concept maps that were produced during the previous interview with that pilot. A large scale reproduction of the computer rendered maps served as the focus of the first phase of the second session interview. The maps were reviewed by the interview team and the specific areas that required either clarification or additional detail were noted prior to initiation of the second session of the interview. The pilot was given the opportunity to make corrections in the map both before and during the second session interview. When the pilot was satisfied with the accuracy with which his knowledge of the target acquisition phase of a tactical air-to-ground mission had been represented, the interview changed its focus.

During the next phase of the interview, the pilots were provided with a specific mission profile which identified the target type, weapon selection, attack geometry and potential threat encounters (see Table 2-2).

With the mission profile serving as the context for the remainder of the interview, the pilots were next asked to verify the accuracy and completeness of a list of decision points between the Initialization Point (IP) and Weapon Release Point (WRP) of the mission. Once completed, a detailed concept map was produced for each decision point which focused

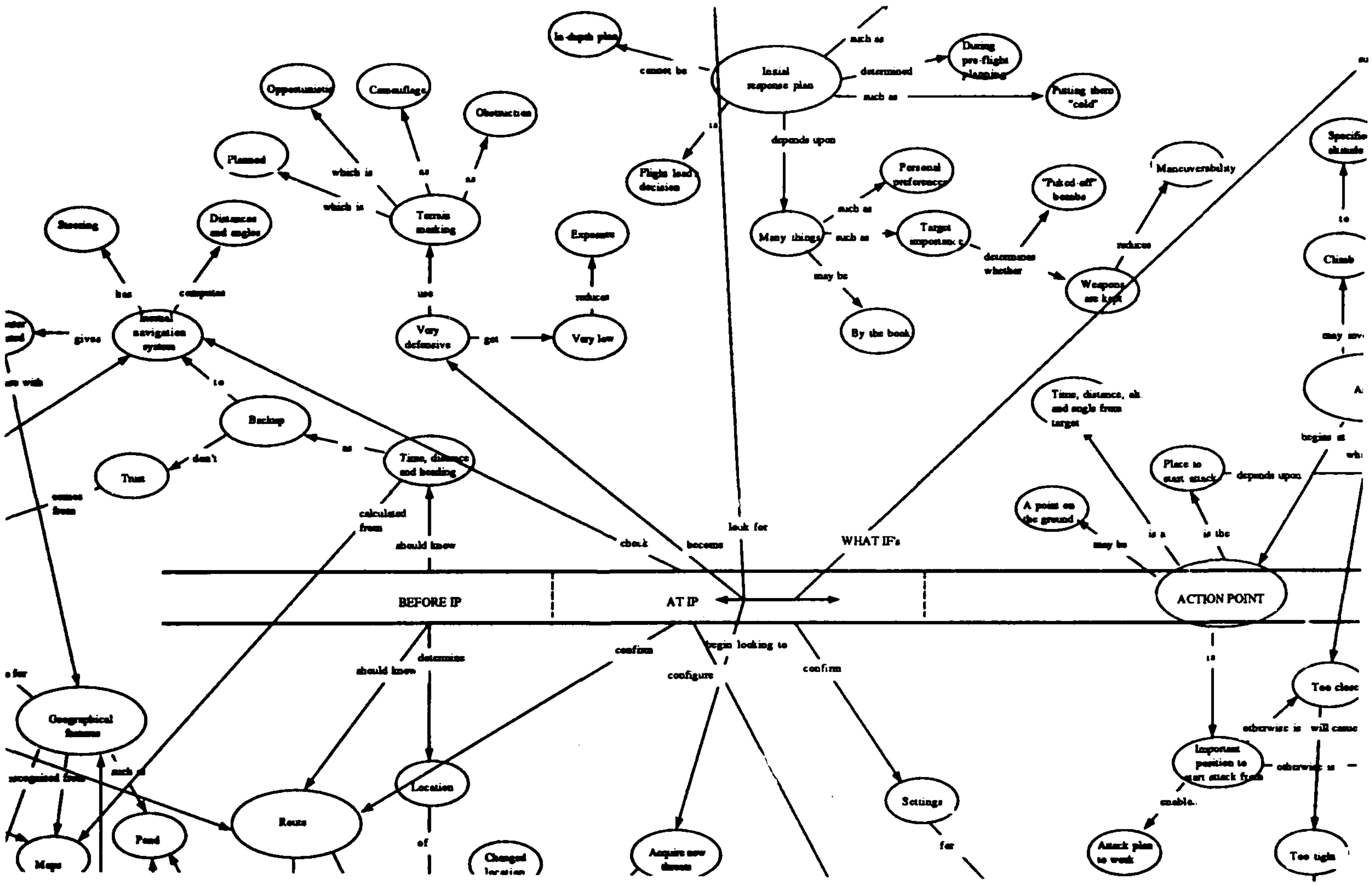


Figure 2-4 Time-line Concept Map Showing a Portion of a Tactical Fighter Mission

TABLE 2-2.

Mission Profile for Second Concept Mapping Session

Mission: A two-ship attack for an interdiction mission. The target area is approximately 100 miles beyond the FEBA.

Target: Destroy 2 POL storage tanks 30 feet diameter x 24 feet tall, separated by 350 feet, and if possible neutralize pumping station. The tanks contain one of the two agents used for binary chemical weapon, it is not especially toxic until mixed, but is very volatile. A large secondary explosion is to be expected with fragmentation up to 5000 feet vertical and 9000 feet horizontal. Fragments are predicted to be back on the ground after approximately 30 seconds. The target area is a rail depot approximately four miles west of a moderately large city.

Weapon Selection: Munitions consists of four CBU-87's per aircraft (CBU-87 contains 202 armor penetrating incendiary, blast fragmenting bomblets). In addition, two Sidewinder missiles will be carried by the aircraft in order to provide protection in an Air-to-air environment.

Time Over Target: The time over target for this mission is 0700 -0715

Weather: The weather for both take off and landing is forecast to be clear with unlimited visibility. The weather in the target area will be limited to a ceiling between 12,000 and 8,000 feet AGL, with visibility limited by 10 to 20 % cloud cover. Winds are variable at 5 to 10 Kts.

Terrain: Just over one hundred miles are planned at low altitude. Low level flight during this portion of the mission will be over flat arid land for approximately half of the time, and over mountainous terrain for the remaining distance. The terrain from IP to target will be mountainous with the target being located in gently sloping terrain.

Table 2-2, continued

Ground Threats: The flight will potentially be within the effective range of long range search radars throughout the mission. SA-6 and SA-8 are known to be located in the target area, with SA-10 and SA-14's along the egress route. Anti-aircraft artillery may also be encountered during ingress, and IP to target run-in.

Air Threats: The initial air threat is posed by MiG-29's that are operating along the FEBA, with a possibility of MiG-23 and MiG-25's in the target area.

Timing: The timing for this mission , while not especially critical, should be adhered to as closely as possible. This is expected to minimize likely threats, and apply ordnance when target is most vulnerable.

C^3: The command and control for this mission will be provided by an ABCCC with appropriate inputs from JSTARS.

Weapon Delivery Method: Double 90, 10° LAB, with a 30 sec delay between flights

Attack Geometry:

Pull Down Altitude:	1500 ft (AGL)
Apex Altitude:	2300 ft
Planned Release Altitude:	1100 ft
Minimum Release Altitude:	900 ft

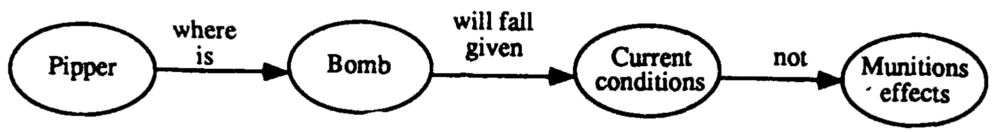
on the information that is used by the pilot to recognize that a decision point has been reached as well as the specific information that the pilots utilize to make the decision. The pilots were probed at this point for details pertaining to: 1) the current source of the information (i.e., the avionic system/sensor that was used); 2) possible improvements in the way in which the information is presented; 3) areas where their performance could be enhanced with the inputs from a Pilot's Associate; 4) ways a Pilot's Associate should interact with the pilot; and 5) possible ideas about function allocation tradeoffs. The information derived from these probes was integrated directly into the concept map that was being drawn.

2.10 Synthesis of Summary Maps

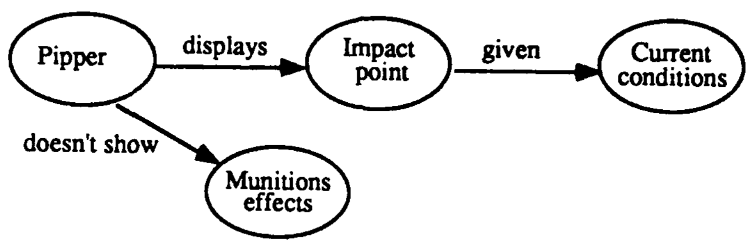
Upon completion of each interview, an extensive map review process was begun. The first step in the process involved a review of the audio tape. During this review, a comparison of the information contained on the tape was made with the information that had been represented with the concept map to insure that all pertinent information was completely and accurately represented. Once the review was completed, the interview session map was transcribed, and then redrawn using a computer-aided drafting application. The process of computer rendering the concept maps proved to be lengthy and time consuming which nevertheless was deemed worthwhile because of the intention to use the maps produced during the first interview as the basis for the second interview. During the process of transcription from the hand-drawn to the computer-rendered map, the content of the maps was examined and subsequently edited in order to insure that all 'node-link-node' units were inherently meaningful, and that the map was free of 'sentence mappings'[7] (see Figure 2-5).

There is no uniform way to map a particular domain, and the maps that various pilots produce are personal expressions of their 'thinking' on the issue of target acquisition at a level of detail not previously available.

[7] Note, that although the viewpoint is said to be that of the pilot's, it does not serve to alter the perspective that is represented using this technique. The analyst, in this case, is attempting to assume the pilot's viewpoint during the performance of a tactical air-to-ground mission, and thus, represents the analyst's perspective of the user requirements.



"Sentence Map"



Concept Map

Figure 2-5 Sentence Map

This particular problem was confronted during the task of summarizing several individual maps into a single composite map. However, since we are particularly interested in the global pattern behavior, and common ways of thinking about that behavior, it becomes possible to initially focus upon the invariants that are found when looking across maps.

The first step in the process of generating a summary concept map involved the identification of the key concept kernels represented in each of the maps (McFarren, 1987). A kernel is simply a cluster of concepts that are all related to a single important concept. The graphical structure of the concept maps, as discussed above, facilitates the identification of key ideas within a subject area allowing the reader of the map to immediately identify global characteristics of the knowledge domain (Lambiotte, et. al., 1989). Recognition of the domain characteristics can then guide the map reader during the extraction of detailed meaning, and facilitate the identification of the concept clusters within the concept map. The key concept within the cluster tended, in general, to be the parent concept in the cluster's hierarchy of concepts. Although the concept clusters were principally identified on the basis of there being "coherent units" within the larger map, several heuristics were used to aid in the identification of the key concept, and the concept clusters. The key concepts tended to: 1) have a relatively large number of connected concepts, resulting from the fact that they had been discussed at considerable length by the pilot; 2) be the parent concept having many generations of related concepts; 3) be a concept that was invariant across maps; and 4) have declarative words appear as a related concept (i.e., "this is important"). The concept clusters are then identified as including the set of relations and concepts surrounding the key concept.

Working independently, two researchers analyzed the individual pilot maps for key concepts and concept clusters. The researcher's assessment of the concept maps and the identification of concept clusters resulted in over 95% agreement. The few disagreements were resolved by reviewing the audio recording of the mapping session in order to clarify specific contextual issues.

Once the concept clusters had been identified in each of the individual pilot maps, they were literally "cut and pasted" to the summary map. Any connections that were broken in the process of removing the cluster from the greater context of the concept map were labeled in order to insure that their context would be preserved. The isolated clusters were checked for internal consistency, and then compared with similar clusters that had been extracted from the other maps. Both the invariants and inconsistencies among the concept clusters were noted.

Once the analysis had been performed on the entire set of concept clusters, they were then aggregated in the form of a summary map. The summary map has the ability to represent either the invariants that exist across the individual concept maps or the full breadth of knowledge that has been captured by the individual concept maps. In order to construct the summary map that captures the invariants, each cluster would be examined and only those found to have common concepts and relations would be included within the summary map. In order to represent the full breadth of knowledge that had been elicited, the clusters would be examined and the full set produced by the union of the individual concept maps would be included in the summary map. The form that the summary map takes depends largely on the needs of the knowledge engineer and the conditions under which the knowledge is elicited. The utility of the summary map which strictly captures the invariants depends upon the size and complexity of the problem domain, and the number of available domain experts. When dealing with extremely large and complex problem domains, or with a limited number of domain experts, the degree of overlap, or invariants found across maps may be relatively limited. Under such conditions, it may be more desirable to produce a summary map that will primarily represent the union of the individual maps.

Due to the complexity of the target acquisition phase of a tactical air-to-ground mission, and the relatively small number of domain experts that were interviewed during the concept demonstration phase of this project, the summary map that was constructed represents the composite of all the knowledge elicited during the interviews with the eight domain experts. However, in addition to representing a breadth of knowledge, a great degree of invariance in the pilot's conceptualization of this mission phase was captured. This finding may run counter to what other knowledge techniques report regarding elicitation of pilot knowledge. Many other knowledge acquisition attempts have suggested that pilot knowledge cannot be compared as a consequence of many insolvable conflicts and disagreements. There were conflicts but our assessment found that the degree of invariance completely outweighed the extent of conflicts between pilots' knowledge. Rather than extracting conflicting knowledge about the mission, the tendency was to find complementary knowledge from each individual pilot. In the event that conflicts are found during the summary process, the concept map provides the shared media wherein the conflict may be described and represented for future discussion and resolution (see Fraser, Hipel, Kilgore, McNeese, & Snyder, 1989; Hammond, 1987; McNeese & Snyder, 1987 for additional material on cognitive conflict resolution).

2.11 Evaluation of the Summary Map

Perhaps the most effective method for evaluating the summary concept map is to begin by assessing the global pattern of concepts as they appear on the map. Starting with global pattern of concepts, an overall impression of the pilots' knowledge concerning target acquisition can be obtained. It is possible to determine the concepts that the pilots consider to be most important and how these concepts relate to other concepts on the map. This review of the information contained in the concept map only begins to scratch the surface of what is there. It is intended to give the reader a sense of how this representation of domain experts' knowledge can be utilized in a variety of ways.

Upon evaluation of the summary map, one of the most important issues relating to target acquisition is the preflight planning. The whole success of the mission depends upon the planning that occurs before the flight leaves the ground. The pilots have indicated that what they do during the flight is (hopefully) making minor adjustments to the plan. Given the current state of the aircraft and its systems, the pilots tended to agree that a major readjustment would be tantamount to aborting the mission. An examination of the map shown in Appendix A indicates that the planning starts with the target and works backwards to the IP, taking into consideration such things as target characteristics, weapon type, threat potential, predicted weather conditions, terrain features, force size, and time of day. These key concepts are related to decisions concerning route selection, attack parameters, and weapon delivery mode, and ultimately influence the selection of the IP, the Action Point, and the WRP.

An evaluation of the concept map should also consider the overall goals and objectives of the technique. The discussion below is not an inclusive analysis of the concepts and interrelationships, but an overview of how this particular concept map achieved the overall goals. A few examples are used to illustrate the utility of the map.

Goals of concept mapping:

1. As noted above, one of the goals of initial concept mapping sessions was to identify global characteristics of the knowledge domain and the overall complexity of that domain. Furthermore, the objective of concept mapping is to facilitate the identification of key ideas (concepts). The types of information found in the summary map of the target acquisition phase of an air-to-ground combat mission provide an overview of the knowledge domain from preflight planning to IP to WRP. This first cut at eliciting knowledge from domain experts provides a foundation from which to identify major problem areas, areas rich for further information requirements analysis by concept mapping, and even information about helpful improvements from the pilot's point of view. The upper right-hand corner of the summary concept map illustrates an example of pilots' suggestions for "possible improvements" to make target acquisition easier. These improvement concepts are related to "sensor" sensitivity, "head-up displays", and "display content" requirements.

2. Another goal of concept mapping is to provide an understanding of the nuances of the knowledge domain. The summary map for the target acquisition task illustrates the potential for variation in the combat environment. It was

noted, for example, on the section of the map showing the concepts and relations for preflight planning/planning considerations that "time-of-day", "weather", "target characteristics", and prediction of "potential problems", among many other variations, impact the mission plan and tactics plans. In addition, the concept map provided information regarding the dynamic environment by the concepts of "compensating for differences", "modifying plans" and "timing problems" that may occur.

3. The identification of problem areas as viewed by domain experts is another goal of knowledge elicitation by concept mapping. There are examples of two types of problem areas in the summary map for target acquisition. One of these areas relates to problems that occur unpredictably during the course of a mission. These problems are addressed under the "preflight planning" concept and are identified as "problems" nodes. Some of these problems refer to "threat encounter", "changes in force size" or possibly problems due to "weather".

Another source of problems that were identified on the concept map relates to the "aircraft systems" concept and the display characteristics of the "HUD". For example, the field of view is "too narrow", it is "like looking through a straw". In noting the cluster of concepts related to possible improvements, the fact that unnecessary data may currently be cluttering the display is indicated by the concepts of "display content" should be "void of unnecessary data". Sensor sensitivity, "see through smoke and water" and incompatibility of "mental model" and display mode are also indications of possible problems that should be addressed in further investigations by the knowledge engineers and the design team, and serve as indications of human factor problems elicited from the pilot.

4. Identification of information requirements is the major reason for acquiring expert knowledge by concept mapping. To

the extent that the domain experts are capable of identifying the information that they use to make the various decisions relating to their mission, it becomes possible to use the concept map to assist in the design of a decision support system and the design of the pilot-vehicle interface. There are several concepts relating to information requirements. For example, some pilots indicated that communications between themselves and their backseater needed to be kept explicit (to prevent a loss of situation awareness). It implies by analogy that the communications between the pilot and an intelligent PA should be similarly explicit. In fact, as the concept map reflects, when the pilots were queried about how they would choose to interact with an intelligent system, they could not imagine feeling comfortable or trusting a system that attempted to infer their intentions on the basis of their actions. The need for explicit communications between an intelligent system and themselves (as pilots) was something that the pilots emphasized rather strongly. They wanted to be able to issue commands to the Pilot's Associate, and receive feedback from the system in order to verify that their request had been accurately executed.

The map is also a source of many other concepts regarding information about the pilots' information requirements. At the more global level, a reading of the concept map indicates that the pilots need to have information specifying the spatial and temporal relationships between themselves and the target, between themselves and the ground, and between themselves and potential threats. In addition the pilots indicate that they want to keep their "heads up", and look out of the cockpit during the entire target acquisition phase of the mission.

5. The final goal, to develop a major communication device in which domain knowledge is transmitted from user to designer, was discussed earlier. The aforementioned work by

Nosek and Roth on the success of semantic networks as a knowledge representation technique for AI indicates the usefulness of this representation scheme from the designer's point of view. That this type of representation scheme can be elicited directly from the domain expert has been demonstrated.

2.11.1 Information Gleaned from the Summary Concept Map

First and foremost, a global description of the target acquisition task was achieved; and that is, the goal of preflight planning is to reduce the unknowns and the decisions that the pilot makes during the mission. Furthermore, the focus of pilot activities during flight is in testing these preflight plans against the reality of the dynamic unpredictable environment of air-to-ground combat missions. In other words, reality testing is an implicit global concern found by concept map analysis.

2.11.1.1 Key Decision Points The domain knowledge represented on the concept map takes many different forms. It depends on the goals of the knowledge engineer, and the design goals, as to just how this knowledge is utilized. Information requirements can be derived based on time-line characteristics, for example. At critical decision points during the mission, concepts and their relationships to other concepts can be examined. There were six major decision points for the target acquisition phase of the mission illustrated on the concept map: IP, Action point, Pull-down, Roll-in, Track point, and Weapon release point. If we take the Pull-down point as an exemplar decision point, then it can be seen that action adjustments are made and that the actions require specific types of information (e.g, current altitude, planned pull-down altitude, parameters pertaining to deviations in planned attack geometry, etc.).

2.11.1.2 Identification of Key Concepts One of the major goals of concept mapping was to identify key concepts of the knowledge domain. Examination of the summary map revealed, as was noted previously, that "preflight planning" drives the target acquisition process. Preflight planning and subordinate concepts take up more than one-half the map and has relationships with all other concepts on the map. This indicates that the "preflight planning" concept has a role as an executive concept. Further examination of the map will indicate that during the actual segment of flight, all activities revolve around the testing and "reaction and readjustment" to accommodate the preflight plan.

Other concepts identified, using the criteria of hierarchy and number of subordinate concepts to choose these key concepts, were:

> Communication: has a subordinate concept noting that target acquisition depends on "effective communication" between "backseater" or "Pilot's Associate". Some of the concepts dealing with communication provide information regarding the pilot's concept of effective communication, including, for example, "gives information" (as opposed to data), "identifies problems", "does not control", and "gives direct commentary".

> Visual Acquisition: concepts that link with "visual acquisition" such as "IP", "pop-up", and the superordinate concept of "target acquisition" and concepts that impact visual acquisition provide the type of information that indicates where the pilot's visual attention must be focused. That is, incoming information to the pilot suffers those constraints. Furthermore, the concept of "visual acquisition" to acquire target has multiple connections to the "preflight-planning" concept. For example, use of the strategy of "big to small" relies on characteristics of "most prominent features" identified in "aerial photos", a major concept of "preflight planning". Pilots also indicated that an adjustment to the initially presented maps during preflight planning must be accomplished via mental rotation during the course of visual acquisition and that one of their statements of need for visual assessment technology would be an 'assistant' which would help them 'calibrate' this mental rotation in flight.

Aircraft systems: the aircraft systems represented on the concept map consists of "HUD", "INS" and "RWR". Those systems provide data/information and present a direct impact on the pilot. The "HUD" is represented in two places on the concept map, once under "possible improvements" and once as a key concept directly related to "aircraft subsystems". Some sample concepts regarding "HUD" requirements note that the "HUD" should "display" and "monitor by exception". This concept addresses the concern that status data not of immediate concern should be suppressed in some circumstances.

2.11.1.3 Problems and Problem Solutions Additional information found on the concept maps refers to the types of problems or tasks the pilot faces during the target acquisition phase of the mission. We noted earlier that much of the summary concept map consisted of discussion about mission concepts that are addressed in the preflight planning stage. Then it was noted that the actual mission consisted of attempting to accomplish the mission according to plan. A time-line representation of mission activities revealed concepts that addressed this constant testing of the mission plan against the reality of the dynamic mission environment.

The concepts that were revealed addressed the types of tasks and decisions that were actually being effected. Concepts such as "compensating for differences", "modifying plans", "making last minute corrections", "planning" and "evaluation" all address the dimension of task type that in turn speaks to the cognitive activities and pilot resources required to accomplish the combat mission. Pilot tasks, therefore, can be classified in terms of management, monitoring, prediction, classification, and interpretation requirements.

These concepts reveal yet another concern for information requirements analysis. The type and mode of presentation of required information must take into account pilot resource requirements. The concept map points out the need for investigation into those questions and, in addition, pinpoints specific concepts related to these requirements. In other words, the PA system decisions can address these concerns based on the concept map.

2.11.1.4 Information Requirements Information requirements are not represented under a concept of "information requirements" but, instead are embedded throughout the summary map. Each major concept has associated with it information that is presented, needed or available and therefore, addressed by the knowledge engineer and design team. For example, "navigation data", "target data", "relationships of self to route" or "ground", "threat position", etc. are represented as concepts under "aircraft systems". "Visual acquisition" relies on information preplanned and out-of-the-window. The information represented in the concept map is interconnected and related to several concepts in a myriad of ways.

As noted earlier, the evaluation of the summary map cannot be comprehensive at this time. We merely wish to provide a focus from which to view the summary concept map. This initial analysis of the pilot-generated concept map provides a systematic method, a front-end analysis, so to speak, to acquire a global view of the characteristics, key concepts and information requirements from the pilot's point of view.

2.12 Observations

Concept mapping has proved to be an effective method for capturing the domain expert's conceptualization of the problem domain. As the preceding section demonstrated, the concept mapping technique has been shown to be an effective method for identifying the user requirements. The concept mapping technique offered the opportunity to access two interrelated processes pertaining to the pilot's conceptualization of the mission. The technique offered the opportunity to acquire the 'information heeded' and 'information remembered' depending upon the level of intrusion (i.e., probing) that occurred during the elicitation process. The information heeded was elicited as the pilot was allowed to "think aloud", wherein there was minimal amount of intrusion by the interviewer. The pilot was afforded the opportunity to spontaneously access information that he or she deems related to the particular phase of the mission that was under consideration without the imposition of the knowledge engineer's point of view (i.e., uninformed access). The concept mapping technique also offered the opportunity to elicit the 'information remembered' as the amount of intrusion was increased. As the pilot responded to a given probe, he or she was encouraged to access specific information (i.e., informed access). This information proved valuable in that it frequently led to the generation of a more highly differentiated concept map.

The issue of validation is a particularly important one, as well as being one that knowledge acquisition techniques have traditionally had difficulty addressing. Following Nosek & Roth's (1990) metaphor which equates knowledge acquisition techniques with conduits of information that may have impurities or filters of some kind, it is important to insure that the transference of knowledge has been complete and without the inclusion or systematic exclusion of impurities. To this date, the domain expert validation remains the single most highly regarded measure of the general success of a knowledge acquisition technique. In other words, the domain experts are usually asked to evaluate the completeness and accuracy of the knowledge representation that is being used to capture the domain knowledge. In this regard, concept mapping has received extremely positive reviews.

The process of concept mapping was unequivocally described by the pilots as a very effective way for them to express their understanding of the problem domain. Unlike the more traditional, and more structured, verbal protocol techniques, they indicated that concept mapping had permitted them to explore the numerous contingencies associated with the problem domain. They felt that their discourse had not been limited by the nature of the knowledge acquisition tool to a single scenario as would typically occur with the use of less open ended verbal protocol techniques. It was generally felt that the concept mapping technique genuinely enhances the presentation of their knowledge. Several of the pilots, in addition to being regarded as domain experts, were also individuals that have had a significant amount of exposure to a wide variety of knowledge acquisition techniques. Their impressions of the concept mapping technique were especially valued, and one of these pilots stated that, "the concept mapping technique was the best knowledge acquisition technique that I have encountered, and I have encountered quite a few. It lets me be sure that you [the knowledge engineer] are correctly understanding what I am saying and not simply hearing what you want to hear."

In addition to the many positive attributes that the concept mapping technique brings to the field of knowledge acquisition, the knowledge engineer considering the use of this technique also needs to be aware of the potential weaknesses that were encountered. First, from a human factors' perspective, it appears that the complexity of the representation may possess problems in terms of comprehension. As stated above, one of the advantages in using the concept mapping technique was said to be the graphical quality of the representation which could enable a viewer of the map to quickly glean the pilot's conceptualization of the problem domain. However, as the complexity of the problem domain increases, there is a corresponding increase in the complexity of the representation of that domain, as reflected in the concept map. There may reach a point at which the concept map has become too complex, with too many concepts and relations for an individual to easily comprehend. The summary map (see Appendix A) may be approaching, or perhaps already exceeding, this critical boundary.

Because the complexity of the map is being driven by the complexity of the domain, any attempt to simplify the map must be carefully considered. Simply parsing the map into subsections on the basis of related concept clusters would offer an intuitive solution to the complexity problem. Unfortunately, the solution would negate one of the principle advantages inherent in this type of representation, namely the ability to see all the relations between the numerous concepts portrayed in a single integrated format. Another intuitive, and potentially more satisfactory solution to the complexity issue would involve parsing the concept map according to its hierarchical organization. In the same way that a highway map of the United States only depicts the principle arteries and those of special significance (i.e., scenic routes, and small but vital routes), the concept map could at one level only represent the key concepts. This high-level map would preserve the global structure of the network of concepts and enable the viewer to appreciate the relationships that exist between the key concepts. Important aspects of the heterarchical structure could also be preserved by including relevant subordinate concepts. When more detailed information is required, the key concepts could be used to access the underlying clusters, in the same way that the global structure of the highway maps are used to reference the embedded street maps that provide a finer grain description.

Another potentially serious problem with the concept mapping technique of which the knowledge engineer needs to be cognizant is the potential loss of the interactive aspects of the technique. The interactive quality of concept mapping is one of the technique's unique attributes that enables the knowledge engineer to have confidence in the veridicality of the knowledge representation. It is important for the domain expert to be continuously attending to the concept map that is being drawn in front of him or her to be correcting any misrepresentations of the domain knowledge. In several instances, pilots were simply relaying their information to the knowledge engineer without simultaneously looking at what was being drawn on the map. Fortunately, the solution to this potential difficultly merely requires the knowledge engineer to occasionally pause in the interview and question the domain expert about the accuracy of the map (i.e., "Is this what you mean?" or "Does this correctly show how these concepts are related?"). These types of probes can also be considered as relatively non-obtrusive, and therefore unlikely to change the focus of the interview to one of informed access, because they do not specifically alter the focus of the expert's attention with regard to the knowledge domain. The result is simply to insure that the concepts the domain expert considers to be important get accurately represented in the concept map.

3 STRUCTURED TASK DECOMPOSITION: AN ANALYST'S VIEW OF THE MISSION

3.0 The $IDEF_0$ Technique

Numerous techniques have been designed to aid in the understanding of complex human-machine systems and processes, and a substantial number of these have been utilized at the Armstrong Aerospace Medical Research Laboratory with varying degrees of success (see Table 3-1). Of these techniques, the Integrated Computer-Aided Manufacturing $Definition_0$ ($IDEF_0$) approach was deemed the most appropriate for representing the analyst's perspective of the user requirements (i. e., the mission description).

In order to generate a functional task decomposition of the tactical air-to-ground mission, the $IDEF_0$ technique was employed. This technique provides a structure and precise semantics that are used in order to control the description of a given system (Marca & McGowan, 1988). The activities or functions of the system are given a semantic label. The activities of the system are then depicted as boxes within a hierarchical representation scheme. By convention, each side of the $IDEF_0$ box has a specific meaning which constrains the type of entity, information or data associated with the activity, and the nature of the interaction, or influence that a particular entity has upon the activity. Specifically, the left side of the box is reserved for inputs, the top of the box for controls, the right side for outputs, and the bottom side of the box is reserved for mechanisms (see Figure 3-1).

The entities and activities of human-machine systems or processes are described using $IDEF_0$ boxes and arrows. The arrows represent virtually anything that has the capacity to influence the activity, or results from the activity that is depicted by the box, including such things as: information, data, plans, technical orders, resources, or the product of the activity. There are four classes of arrows corresponding to the four sides of the $IDEF_0$ box. The input arrows (those connecting to the left, or input side of the $IDEF_0$ box) are defined as representing those things that are used, and/or transformed by the activity. The control arrows represent the types

TABLE 3-1

System Modeling and Knowledge Representation Techniques
Previously Used at AAMRL

1. **Outlines**

Used for: task analysis, goal hierarchies, work breakdown
Primary data structures: text
Representations of: top-down hierarchy
References: Various

2. **Block diagrams**

Used for: functional diagrams, organizational diagrams
Primary data structures: blocks, directed connections, explicit levels (if hierarchical)
Representations of: functional elements, organizational elements, top-down hierarchy, connectivity, associations, feedback loops, command levels, processes
References: Various

3. **Task/Decision Trees**

Used for: task analysis, decision analysis, work breakdown
Primary data structures: blocks, undirected connections, implicit levels (if hierarchical)
Representations of: top-down hierarchy, logic links, inferences
References: Awad (1979); Wohl and Tenney (1987)

4. **Program Evaluation and Review Technique/Critical Path Methods (PERT/CPM)**

Used for: task analysis, resource analysis
Primary data structures: task identifiers, directed connections, paths
Representations of: bottom-up tasks/events, resources, performance specifications/timing
References: Awad (1979); Wohl and Tenney (1987)

Table 3-1 continued

5. **State Transition Diagrams/Markov State Models**

Used for: analysis of state transitions within a system or process
Primary data structures: system state identifiers, directed connections, implicit transition conditions, probabilities
Representations of: system state transitions
References: Shaw (1987)

6. **Flow Charts**

Used for: information flow analysis
Primary data structures: function blocks, directed connections, decision points, sources/sinks, logic elements
Representations of: functions, decisions, control flow, input/output, terminal points (entrance/exit)
References: Wohl & Tenney (1987)

7. **Data Flow Diagrams (DFD)**

Used for: information flow analysis
Primary data structures: task/process circles, directed connections, source/sink blocks, information/object storage points (time delays)
Representations of: tasks, processes, procedures, data stores, external organizations, flow of information, flow of materials/objects, input/output, flow timing
References: DeMarco (1978); Awad (1979); Wohl &Tenney (1987); Martin (1989)

Table 3-1 continued

8. Structured Analysis and Design Technique/Integrated Computer Aided Manufacturing (ICAM) Definition$_0$ (SADT/IDEF$_0$) diagrams

Used for: hierarchical functional analysis of activities,work breakdown
Primary data structures: activity blocks, directed connections (inputs, outputs, mechanisms, controls), explicit levels (of hierarchy), implicit priority levels (of activities)
Representations of: top-down hierarchy, tasks, activities, processes, functions, input/output (status), consumable/nonconsumables resources, controls, priority
References: Ross & Schoman (1977); Hoyland, Evers, & Snyder (1985); Wohl & Tenney (1987)

9. Structured Analysis of an Integrated Network of Tasks (SAINT)

Used for: structured, event-driven simulation of task networks
Primary data structures: task nodes, information attributes, resource attributes, system attributes, task timing, branching criteria, resource clearing, state variables, state variable regulators, task monitors, moderator functions, probability distributions, network modifications, output options
Representations of: task networks, complex systems
References: Wortman, et al. (1978); Snyder & McNeese (1987)

Table 3-1 continued

10. Petri Nets/Colored Petri Nets (CPN)

Used for: dynamic queuing network models
Primary data structures: tokens, places, transitions, arcs, rules, attributes, ordered sequence of transitions/places
Representations of: forces, messages, data, intel, personnel, equipment, facilities, functions, procedures, processes, communication links, direction, coordination, control, missions/complex systems
References: Wohl & Tenney (1987); Meta Software Corporation (1989)

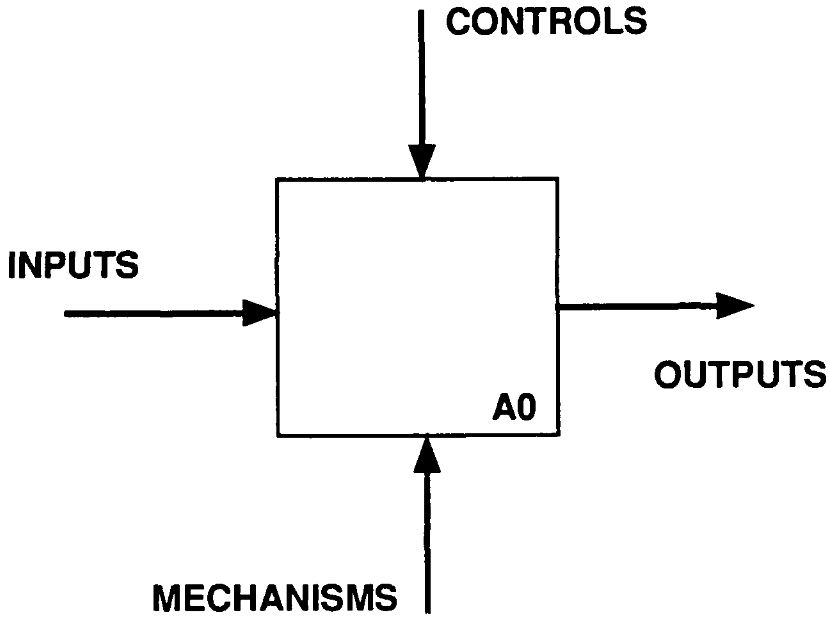


Figure 3-1 IDEF$_0$ Syntax

of things that constrain, or control activities, such as plans, technical orders, or rules of engagement. The output arrows represent the things into which the inputs have been transformed, or the product of the activity. For example, if the input was a mission status, the output might be the change in that status resulting from a performance of the identified activity. Lastly, the mechanism arrows represent the mechanism or resources that are being utilized by the system in order to accomplish the activity that has been depicted by the $IDEF_0$ box.

The influence that different activities have on each other take many forms, and the $IDEF_0$ technique has been designed to describe and represent the various types of interactions that are likely to occur. The arrows are used to represent the relationships that exist between the activity boxes, or in other words how the activities influence each other. For example the output of one activity may be required as an input to another activity, or the output of one activity serving as control information that governs the performance of another activity. In addition, although perhaps rarely, the output one activity has produced may become a resource that is employed by another activity. The $IDEF_0$ technique is also capable of depicting various feedback loops or iterations in the execution of one activity that are being influenced by the output of a separate activity.

Each function of the system or process is decomposed into a series of interconnected $IDEF_0$ diagrams that graphically depict the characteristics of the function and relationships between functions (see Figure 3-2). The overall system or process is represented as a single activity in a top-level (Level 0) diagram. A key characteristic of the $IDEF_0$ model is that it is hierarchical in nature. Each layer is an elaboration of the layer (function) above it. Each child inherits the attributes of its parents and passes on its own attributes to its children. Thus, the architecture supports the establishment of a top-down design which can be used to establish a prioritization of constraints and controls based on hierarchy. The functional requirements are developed by determining the specific tasks, decisions, information requirements and pilot actions occurring during the performance of the mission.

The activities or functions that are accomplished by the system can be broken into sub-level layers by means of a functional task decomposition.

In this decomposition, each activity is defined as a function or task, and is represented with symbols that graphically depict the interactions and relationships that exist with other tasks or functions. Each function is dependent upon various inputs, provides particular outputs, operates via various mechanisms and performs its activity according to specified restrictions, guidelines, controls and constraints. For every activity (function or task) key decision elements can be identified and precise descriptions of the network of functions, relations, and corresponding parameters can be determined.

In addition to decomposing the activities that are performed by the system, the $IDEF_0$ technique also allows for both the decomposition and integration of the various entities that influence the system's activities. The arrows in an $IDEF_0$ diagram typically represent a collection of things having multiple sources and multiple destinations, and as a consequence, the arrows can be represented as branching apart and joining together in complex ways.

3.1 An $IDEF_0$ Description of the Tactical Air-to-Ground Mission

The construction of an $IDEF_0$ description generally requires extensive domain knowledge, and the process of using $IDEF_0$, as a consequence, generally begins with the collection of that knowledge (Marca & McGowan, 1988). For the present context, the information was provided by one of the authors, John Duncan, who has extensive experience in the area of fighter pilot training, simulation, modeling, and avionics systems design. This knowledge and experience with fighter aircraft operational requirements and avionics engineering design is regarded as crucial for the performance of the task analysis, requirements definition, and information modeling.

Because $IDEF_0$ is only capable of representing a single purpose, viewpoint, and context, it is important that these attributes be clearly defined before constructing the diagrams. The decomposition of the activities being represented in an $IDEF_0$ model typically proceeds until the analyst has either exhausted the extent of his or her knowledge of the system, or until the model has satisfied its stated purpose.

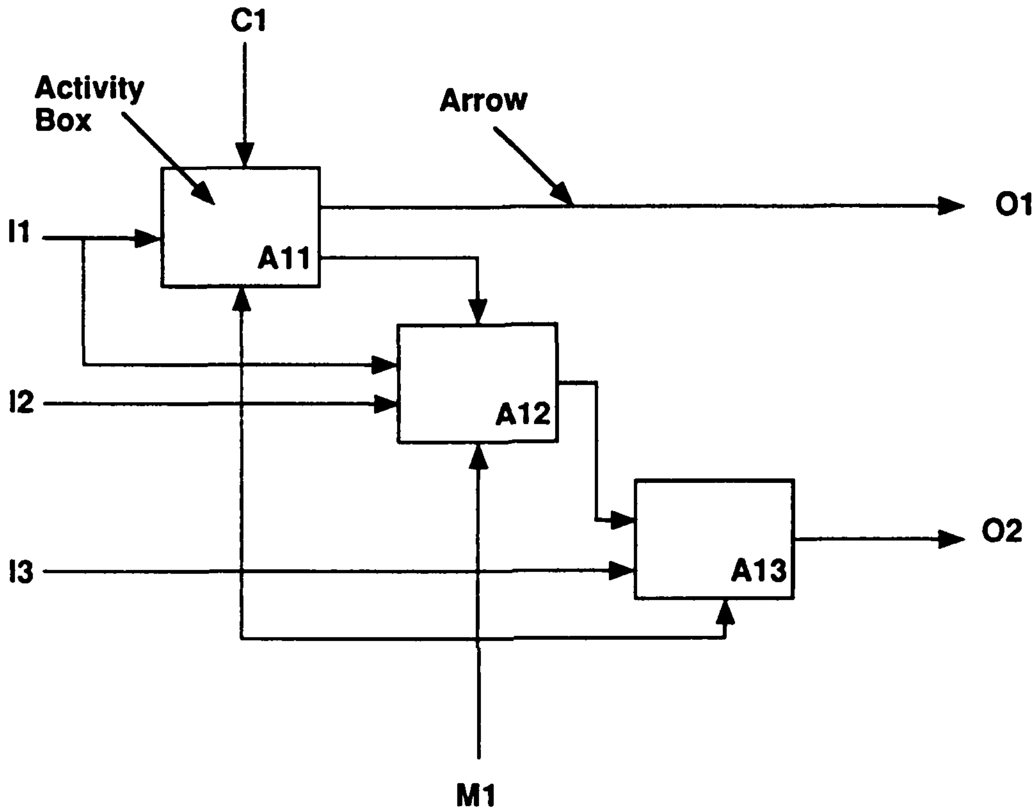


Figure 3-2 $IDEF_0$ Hierarchical Decomposition

The $IDEF_0$ representation of the tactical air-to-ground mission is provided in Appendix B. The viewpoint was assumed to be that of the pilot's.[8] The context for this $IDEF_0$ model was identified as being a tactical air-to-ground mission as performed by an F-16 type aircraft with Continuously Computed Impact Point (CCIP) and Continuously Computed Release Point (CCRP) weapon delivery modes, and aircraft fire control, radar, and related weapon systems having comparable accuracy and capabilities. An emphasis was placed on the associated mission functions occurring during the ingress to the target IP phase, the target attack phase, and the egress phase. This representation depicts the activities that the pilot must accomplish in order to successfully complete the mission. A determination of the decisions, tasks, information requirements, and pilot actions that occur during the performance of a tactical air-to-ground mission was accomplished during the decomposition process. Task performance was modeled down to the switch activation level in order to demonstrate the model's capacity of providing a means for performing analyses on such things as workload, computer control of switches, panel layout, control mechanisms, and task/function allocation.

In addition to an $IDEF_0$ model of a tactical air-to-ground mission, an $IDEF_0$ Data Dictionary was created to provide definitions for each function within the $IDEF_0$ Tactical Air-Ground Mission decomposition (see Appendix C). Unique Inputs, Outputs, Controls/Constraints, and performance Mechanisms were described and descriptions of pertinent parameters are generated for those functions requiring elaboration.

3.2 Observations

3.2.1 Strengths. A primary characteristic and strength of the $IDEF_0$ technique was its incorporation of trait inheritance through a hierarchy of functional decompositions and relationships. For the purposes of the tactical air-to-ground mission, there were several continuous concerns

[8] Note, that although the viewpoint is said to be that of the pilot's, it does not serve to alter the perspective that is represented using this technique. The analyst, in this case, is attempting to assume the pilot's viewpoint during the performance of a tactical air-to-ground mission, and thus, represents the analyst's perspective of the user requirements.

involved with the operation of the aircraft and success of the mission. These items are persistent in nature, and at various times took precedence over all other actions. For instance, of prime concern at all times are those conditions that are immediately life-threatening, or potentially fatal to the pilot, such as catastrophic aircraft failure, or impending threat encounters. In those cases, aircraft/pilot survival actions take immediate precedence over ongoing tasks - the pilot must perform those actions that will alleviate the circumstances that are life threatening at the expense of the current tasks and possibly mission goals. The structure of $IDEF_0$ easily allowed high-level traits to be represented, while the analysis of other functions were traced to lower levels.

When the $IDEF_0$ was expanded to the lowest levels, the systems management actions and discrete pilot actions, including switch operations of particular equipment, were explicitly shown. By employing this method of increasing functional detail, the $IDEF_0$ diagrams accurately represented the functional tasks and operations performed by the pilot. Additionally, the corresponding mechanisms and controls which interacted with tasks and operations were portrayed at various levels in the $IDEF_0$ hierarchy. Taken together, these attributes comprise an analyst's perspective of the mission and generate the capability to perform analysis on several aspects of the tactical air-to-ground mission.

3.2.2 Shortcomings. One of the primary shortcomings of the $IDEF_0$ analysis was that decision making criteria are only evident, if present at all, at the lowest level of the diagrams. The functional results/outputs were clearly defined, but neither the cognitive processes nor the perceptual-action-environmental interactions necessary for complex flight were apparent. The diagram provided a functional knowledge representation that was oriented toward resources and results, but failed to show: 1) the underlying decision rules, criteria, or alternatives; and 2) the perceptual discriminations necessary for situated actions.

Another significant weakness arose from the fact that $IDEF_0$ is structured with precisely defined boundaries. This weakness becomes a major problem for the modeling of extremely complex and dynamic environments where boundaries are fluid, and the task priorities, conditions, and interrelationships are continuously changing.

Another difficulty encountered with the use of the $IDEF_0$ technique occurred with the representation of some of the discrete parameters involved in lower level functions. For a highly complex task involving a myriad of data, decision making, and possible outputs, increasing levels of detail were required to create lower level diagrams. As the information increased, the advantages of the $IDEF_0$ as a graphical information representation was negated. When upper level traits are replaced with more detailed and explicit traits, the representation grew exponentially larger, more complex, and more cryptic. As the complexity and level of abstraction increased, the diagrams became more difficult to understand, and the ability of the expert (pilot) to provide direct meaningful input was impeded. Consequently, the need to accurately describe a process is in direct conflict with the goal of creating an easily understood graphical representation that can be readily understood and critiqued by the domain expert. The simplicity offered by pictorial representation was easily overwhelmed by the use of annotation and symbology.

In addition, increased detail led to unlinked (tunneled) parameters in many cases. This tunneling made it necessary to audit and analyze unlinked parameters carefully when validating and verifying the $IDEF_0$ representation. As a consequence, it became difficult to independently validate the information that was represented, and for this reason, the diagrams remain representative of the analyst's perspective of the user requirements rather than depicting the user's perspective of his or her own requirements for the task.

4 STORYBOARD PROTOTYPING: A DESIGNER'S VIEW OF THE MISSION

4.0 Design Acquisition

As was previously mentioned, the design view of the mission is a very critical component of the overall framework for the knowledge and design acquisition methodology. Design acquisition begins to provide the perceptual basis for placing both domain expert and knowledge engineer within the same representational context that has contributed to the development of expertise by the domain expert. The challenge which the design acquisition methodology has begun to address involves the innovative utilization of the pilot in the design process. Typically, pilots have only been used as reviewers of a previously established design prototype, or knowledge representation. During the review process, the pilots may be presented with data or information that is very often conveyed to them by means of representational structures that are opaque and difficult to comprehend. On the basis of these opaque representational structures, the pilots are asked to comprehend what is being implemented, or to predict the effects that a new technology will have on their piloting behavior, and then provide their tacit approval.

Kantowitz & Sorkin (1983) suggest that the first commandment of human factors is to "honor thy user." Simply having a Pilot Review Board is not likely to satisfy the spirit behind the commandment of honoring thy user, as it fails to provide the opportunity for pilots to review, design, and evaluate in a manner which is appropriate and natural for them. Hunt (1987) believes that to produce an effective and efficient interface, system users must be involved, in an appropriate manner, from the very first step of the design. Andriole (1989) indicates that one of the difficulties in pursuing this challenge is that users are notoriously inarticulate when it comes to defining their needs. Design acquisition must begin to acquire knowledge from pilots in a form that is natural to their way of understanding flight requirements (in other words, knowledge as design within a given context).

In particular, our framework elicits design knowledge by placing the pilot in the role of the designer to design the interface which connects the pilot with his/her operational environment. By placing the pilot in this role, the knowledge engineer may then learn the pilot's information requirements by noting the design attributes which pilots include in their design of an interface which they consider suitable for flying a tactical fighter during a given mission segment. Hence, the design view of the mission begins to unfold in iterative fashion. Knowledge transpires as actual design attributes which are spontaneously evoked from a partial representation of the real world settings.

4.1 Storyboard Tools and Techniques

The initial tool used to implement the design acquisition methodology is "storyboard prototyping". Storyboard prototyping can be defined as an interactive technique that weds multiple methods for requirement gathering, representation, and conceptualization into a single powerful tool for identifying and validating requirements before any expensive programming needs to begin. The power provided by storyboard prototyping can be described along five facets. First, it provides the medium to express concepts, ideas, and thoughts as visual, auditory, and tactile designs. This replaces the semantics of the other representational models of the mission with real world design and/or symbolic objects. These objects are not language-based but are instead directly perceivable by the senses. Figure 4-1 illustrates this transformation. Second, storyboards provide the type of environment for erecting, changing, evaluating, and saving design cases. The storyboards are housed on a Macintosh/multi-media environment which provides playback/slideshow simulations. Third, the storyboards allow a rapid evaluation of pilot-vehicle interface prototypes. This means that pilots (and other design team members) can easily and inexpensively iterate and modify the various design prototypes. A given prototype can be used as the baseline design in order to stimulate the

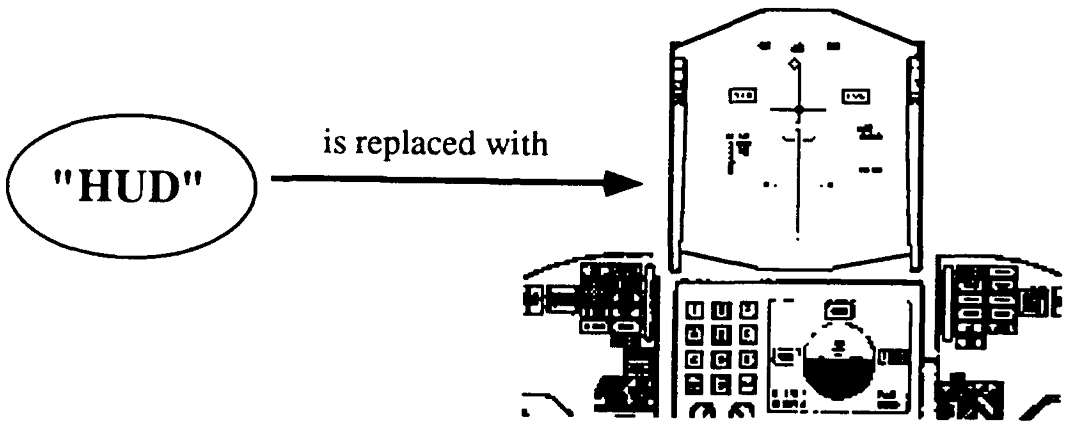


Figure 4-1 Transformation from Semantic to Isomorphic Representation

exploration of divergent design solutions. Fourth, design storyboards facilitate problem identification for a given design prototype. In this situation, the user, problem type, and the design become unconstrained variables. In other words, the design storyboard may start with a given pilot, a particular baseline design, and a previously identified problem, and then proceed to alter these factors. The intent is to unconstrain the development of the design, to include many pilots who will generate many designs and elaborate upon the problems that they identify with other design cases. The result is what we refer to as case-based design.

Case-based design allows one person to view another person's design storyboard to generate a response as well as his or her own solution to the design problem. Any viewer of the design storyboard can document his or her rationale for any changes or endorsement of other design cases. This capability affords everyone involved in the design acquisition process the opportunity to generate designs and provide explanations for their particular model of the world with each explanation being directly linked with the specific design attribute. Hence, the design and the explanation of the design can be expressed in an explicit communication media in which all cases are available to any individual utilizing the design storyboard utility.

Because the development of particular design cases are accessible to any pilot or other user of the design storyboard utility, the characteristics of the 'user model'[9] inherent within the PVI design becomes much more explicit. Vaubel & Gettys (1990) define the user model as an abstract representation of the user that models those aspects of user behavior and knowledge needed by the interface. They also suggest that the user model must be employed by an adaptive interface in order to adapt itself to the user's needs. Often the model of interaction between the pilot and the PA is amorphously stated and unavailable to designers, pilots, or analysts. The nature of the representational models used in this framework allow the individual using this utility to begin to experience and understand the user model as it is manifest in the various design cases. Because the PA will

[9] User model refers to human-computer interface models (Card, Moran, & Newell, 1983), mental models (Johnson-Laird, 1983), intelligent-student models (Sleeman & Brown, 1982), and mindware inferencing (McNeese, 1986).

involve adaptive interfaces, the experience of interacting with an explicit user model begins to expedite how the PA should adapt given: 1) the user's concepts, functions, needs; and 2) the design cases implemented.

Finally, the fifth facet of design storyboard power is that the representation simulates change in a graphic format through a given time sequence. One analogy might be to look at the storyboard as a comic strip unfolding. It has a sequence with a specific content within each frame that tells a story. The storyboard shows something rather than just describing that something with words. Imagine reading the comics without the graphic frames present. The visual aspects of the comic strip are often what generates the humor. Likewise, the storyboard provides the basis for experiencing the design as opposed to simply reading a description of the design specification. The medium by which the storyboard utility shows something is not limited to the visual modality (i.e., static graphics, text and video-based presentations) but may be auditory or tactile in nature. The time sequence function enables the storyboards to behave as a 'primitive simulation' providing the viewer with the ability to see the changes in design elements that occur over time. This adds a dynamic characteristic to the design model and shows how the interface must change at different phases of interaction with an intelligent system in order to accommodate the pilot's needs.

4.2 Storyboarding the PA/PVI

Our use of the design storyboard utility was intended to supply a designer's view of the target acquisition phase of a specific air-to-ground mission (see Appendix D) and to evolve time sequenced PVI design frames (see Figure 4-2).

In order to accomplish this, pilots were placed in the role of designers. The intention was to extract from the pilots what they felt to be the information requirements that enabled them to transition between the

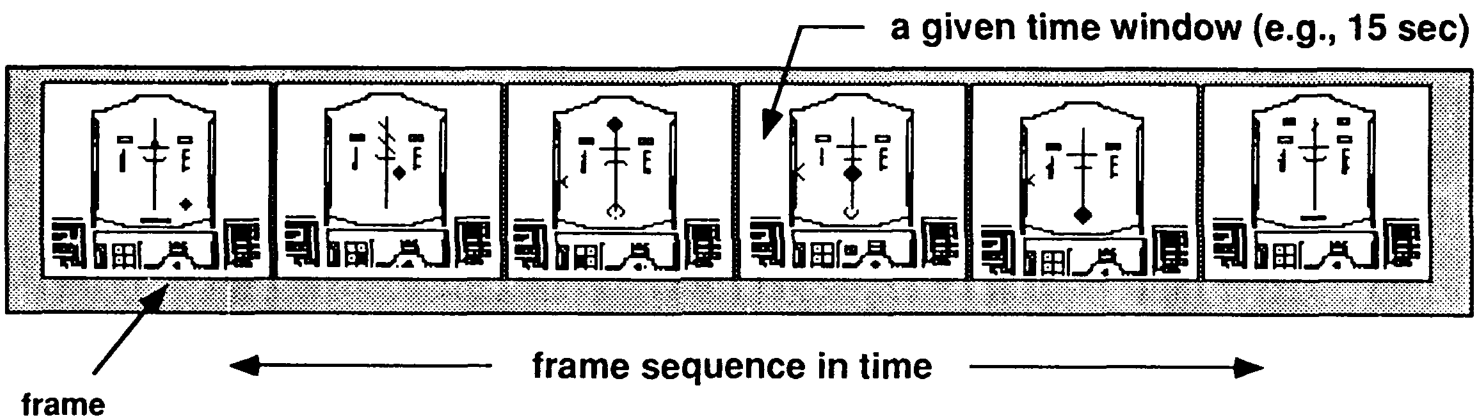


Figure 4-2 Storyboard Time Sequence

various decision points[10] during the target acquisition phase of the mission. In other words, the pilots were asked to describe in detail the information they needed to identify a particular decision point, as well as the information they needed to control their current course of action. For instance, the pilots were asked to describe the information they used to identify when they had reached the action point (one of the decision points between the IP and WRP) and what information they now needed in order to perform the actions that they were initiating at this decision point.

Five of the eight pilots that had been previously used during the concept mapping phase of the project were used to elicit specific design knowledge. The procedure for acquiring design knowledge from pilots transpired after the completion of the second concept mapping interview. During the design acquisition phase, we continued to concept map decision points and information requirements that the pilots' identified. Although there was some disagreement regarding the source of the information that was being displayed (owning to the fact that the same information is frequently available from more than one display source), there was complete agreement among the pilots regarding the specific decision points between the IP and WRP (see Appendix A for a concept map representation of these decision points).

After the pilots had identified the decision points and elaborated upon the associated information requirements, the pilots were placed in the role of a designer. Until this point in the acquisition process, a non-specific mission was used in order to establish the context. This lack of specificity, it is believed, had given the pilots the flexibility to discuss the concepts that they considered to be most important for the target acquisition phase of a tactical air-to-ground mission. The storyboard utility, however, required an increased level of specificity in order to elicit design attributes which could be meaningfully tied to a specific set of environmental and mission-related conditions. Thus, in order to facilitate the use of the pilots in the role of designer, the pilots were given a specific mission plan (complete with attack geometry) to review. This plan was developed with the assistance of fighter

[10] A decision point was defined for the pilots as being the point at which they transitioned from one course of action to begin another separate course of action. For example, the point at which the pilot decided to stop a terrain following flight and begin a rapid ascent would constitute a decision point.

pilots for authenticity purposes. After the pilots had reviewed the mission plan, they were asked to design a sequence of storyboards for the target acquisition phase. A separate storyboard, containing the information that was required at that point, was generated for each of the decision points during the target acquisition phase.

On the basis of the information that had been gleaned during the concept mapping sessions, it was decided to confine the storyboard designs to either a full windscreen Heads Up Display (HUD) and/or a Helmet Mounted Display (HMD). This was due to the fact that all of the pilots had remarked that they would like, if it were possible, to keep their heads up and looking out of the cockpit during the target acquisition phase of the mission.

The handcrafted storyboard procedure involved placing a three foot wide piece of paper in front of each pilot for each of the decision points. They were then asked to draw in what they wanted to see from the display surface in order to assist them in the performance of the mission. The pilots were given the freedom to have either a 180° wide field of view HUD, a HMD, or both. Pilots were continually asked to explain what they were doing and to provide a rationale for each display element created. The pilots were also asked for information that they would prefer to have presented in either an auditory/voice, or tactile format. In essence, we were requesting pilots to translate their verbal enunciation of information requirements gathered early in the concept mapping session into actual design frames for each decision point of the target acquisition phase of the mission.

After each of the pilots had participated in the design acquisition session, their handcrafted design storyboards were integrated in the form of an online <u>summary storyboard</u> using Silicon Beach, Inc.'s <u>Supercard</u> application software (Appendix D shows the summary storyboard frames which have been developed). The summary storyboard constituted a compilation of the replicated ideas as well as the inclusion of the innovative aspects taken from each storyboard. The summary storyboard as well as individual pilot storyboards were saved as specific design cases for later iterations of the design acquisition process. The next step in this process requires the summary storyboard to be validated by our initial pilots for further refinements and elaborations.

Once refined, the summary storyboard will be integrated with the other mission perspectives derived from the pilot's conceptualization of the mission (represented in the summary concept map) and the use of a structured task decomposition (e.g., the IDEF0 representation). Figure 4-3 illustrates the overall aspects of the design acquisition session.

At this point, the summary storyboard would be in a state where it would be ready for dissemination to other pilots for additional iteration and review, thereby enabling knowledge as design to evolve.

4.3 Observations and Results

The use of storyboards has reinforced our ideas regarding the importance of affording pilots the opportunity to translate their conceptual knowledge and expertise into a representation and design prototype which could be perceptually experienced by other utility users. Consequently, one observation which could be made is that the storyboarding created a medium wherein perceptual judgments could be shared or transmitted between the knowledge engineer and the pilot. For example, rather than just telling the knowledge engineers about an information requirement the pilot could actually show him or her by drawing a graphical representation not only what, but also, how they would like to have the information portrayed. The goal of using knowledge as design was thus accomplished as design acts to make the knowledge extant.

It was often initially easier for a pilot (or for that matter, any user) to analyze what is wrong/right with an example design than it was to generate their own designs from scratch. Through an exercise of analysis, synthesis is born; thus, when the pilot appeared to be having difficulty generating design ideas, he or she was given the opportunity to review and critique a straw man design (i.e., current aircraft displays) as a way to begin the generation and discovery of their own designs. This proved successful as it apparently provided the pilots with a direct opening into their personal experience which in turn gave them a basis to drive their

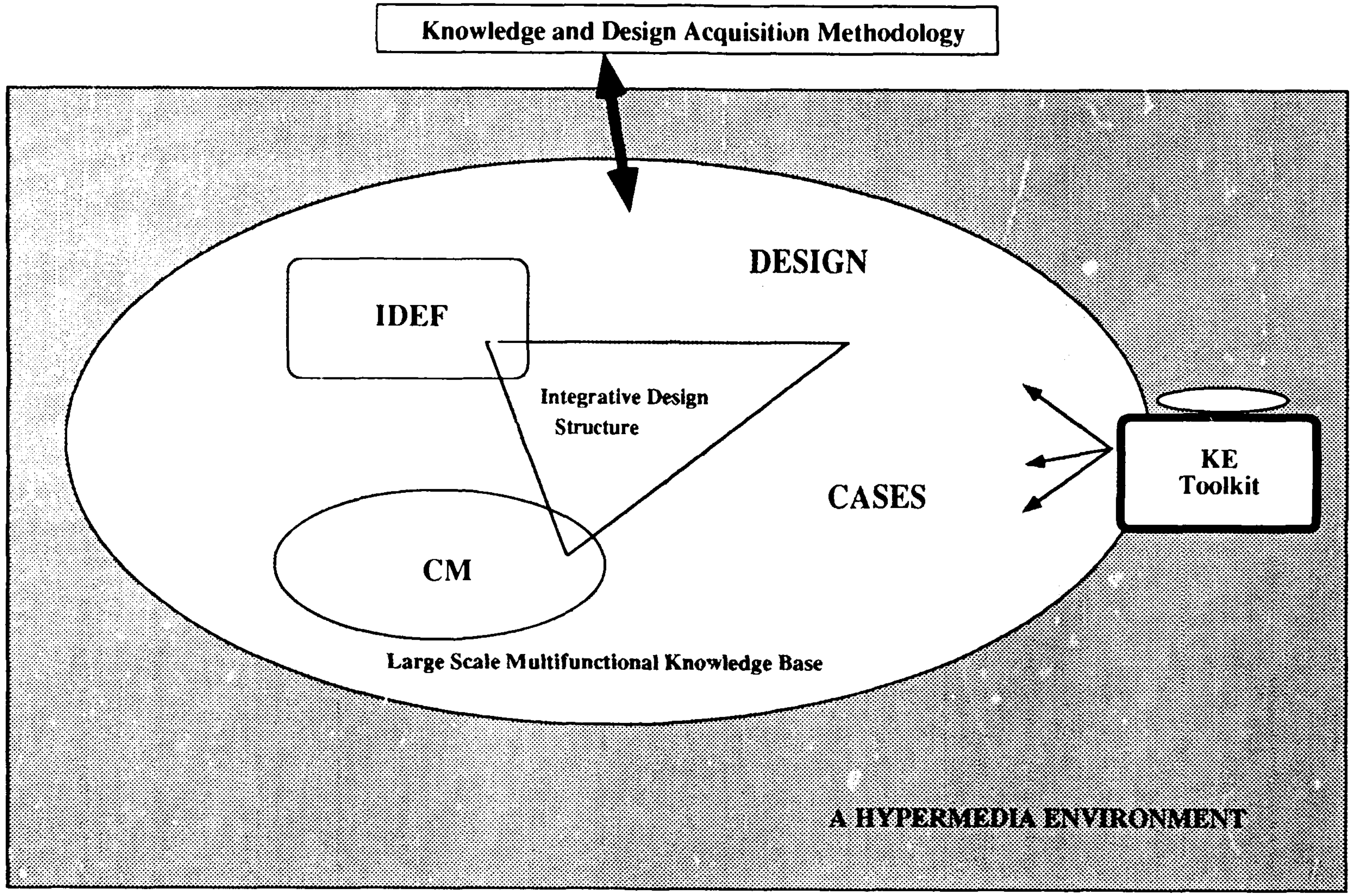


Figure 4-3 Knowledge and Design Acquisition Methodology

design. The pilots tended to generalize from their experience in order to create designs which would more effectively satisfy their own information requirements. In all instances, the pilots were able to transition from analysis to synthesis in order to complete the design task. These observations have led us to the conclusion that, when given an opportunity and the proper set of tools, pilots were able to perform effectively in the role of designers.

Often the argument is made that pilots only have a limited understanding of technological advances and consequently would fail to know what is required for the PA. Our results suggest that pilots are richly endowed with what they need for particular aspects of the mission in terms which would help them. They were able to communicate these needs, and in many cases, design the interface themselves. We believe this is the correct approach to the design process. Technology should not drive the pilot; but the pilot, on the basis of his or her needs, should be the main force which drives the development of the PA. The point is to preserve and represent these needs, such that they can be given to other design members for input. Concomitantly, the pilot, interacting within this knowledge and design acquisition framework, should have access to other PA team member views of the mission. In this way, learning becomes paramount and an active part of design; design ideas are distributed across the PA team and act as generators of potential knowledge/design acquisition to create large-scale knowledge bases suitable for deriving the PA.

In this design acquisition session, it was also observed that perceptual-based design is a main driver for an integrative design structure tying all the mission views and representations of those views together. We observed that as a part of explaining or providing rationale for a design element, the pilot naturally established links to their concept maps, both in terms of information requirements and as a guidepost which fueled the design generation process. This natural connection between the semantic and perceptual representations of knowledge, gauged in accordance with specific decision points and information requirements, underlies the integration of the disparate knowledge representations. When pilots begin to make the connections between their thoughts and the way these thoughts should be transformed into designs as they perform, a sound basis for configuring a PA has been established.

An intelligent system must be able to interface with the pilot in terms of both his/her general and specific knowledge about the given phase of the mission, as well as the cockpit design itself. The software which underlies the PA must capture multiple views of how a pilot envisions the mission as well as the associate itself. The power of the knowledge and design acquisition methodology is in providing an interactive medium that directly connects the pilot to the design of an intelligent sytem which will provide him/her decision support. By capturing the pilot's knowledge and design, the PA has obtained a 'mental model' and 'pilot interface' baseline for further development.

5 TOWARD AN INTEGRATIVE STRUCTURE

5.0 The Integration of Three Different Knowledge Representations

The advanced knowledge and design acquisition framework has led to three distinct representations of the target acquisition phase of the air-to-ground mission: concept maps, IDEF diagrams, and design storyboards, as propagated from direct pilot input. One of the goals of this effort, as it continues, is the development of an integrative knowledge structure within the domain of a hypermedia environment. This structure would allow the establishment of the inter-connective linkages across the three knowledge representations, and provide the means for understanding the impact that the elements of one representation would have upon the elements of the remaining two representations. The proposed structure involves the creation of linear and non-linear associations among the various elements of knowledge representation. The intent is to allow any given user of this utility (e.g., a human factors engineer, a system designer, a pilot, etc.) to gain direct access to multiple knowledge representations.

This access to the knowledge representations would enable the user of the utility to both navigate between the different forms of knowledge by means of the existing linkages and establish new linkages when deemed appropriate. Whenever a link is traversed or created the user would also have the option of adding text comments for rationale, questions, or explanation. After a user has completed a session in the integrative structure their changes, additions, and search through the structure would be saved as a new case of the integrative structure. As the number of users increases, the number of linkages between the representations will increase, thereby fostering a corresponding increase in the breadth and depth of the actual knowledge base.

5.1 Navigating Linkages

Given that there are three representational schemes within the integrative structure, the user would be able to enter the structure at any given element within a scheme. If an element in a knowledge representation (i.e., such as a concept from within a concept map) has already been connected to another element of knowledge (i.e., a design element from within a design storyboard), that linkage would be identified as existing and available to the user (e.g., with a button or hot spot). When the button is activated, the user would be transported from the first knowledge representation to the second associated knowledge representation as a way of demonstrating the relationship that exists between the two representations.

For example, if the user of the utility were examining the design storyboard produced by one of the pilots, the user would be able to move from a particular design element in the storyboard, to the related concept within a concept map. This journey from the storyboard element to the concept map would presumably provide the user with the insights (or conceptualizations) that led to the inclusion of that design element within the storyboard. For instance, if the user were interested in finding out why a visual offset point had been included in the storyboard, he or she could be directly transported to the portion of the pilot's concept map which discussed the limitations of the target designator box, and the need to have an additional visual referent (the offset point) that would be tied to an easily identifiable environmental feature.

5.2 Establishing Linkages

Using this integrated structure would enable the viewer to simultaneously view multiple knowledge representations and establish links among elements of the disparate representations. Note that in the process of establishing linkage, the user has the option to document any rationale, guidance, or comments associated with the link. These "link characterizations" would be saved as part of that user's case, and would then become accessible to other users of the integrative knowledge structure.

Figure 5-1 provides a graphic illustration of the integrative structure in terms of the overall knowledge space available for conceptualization,

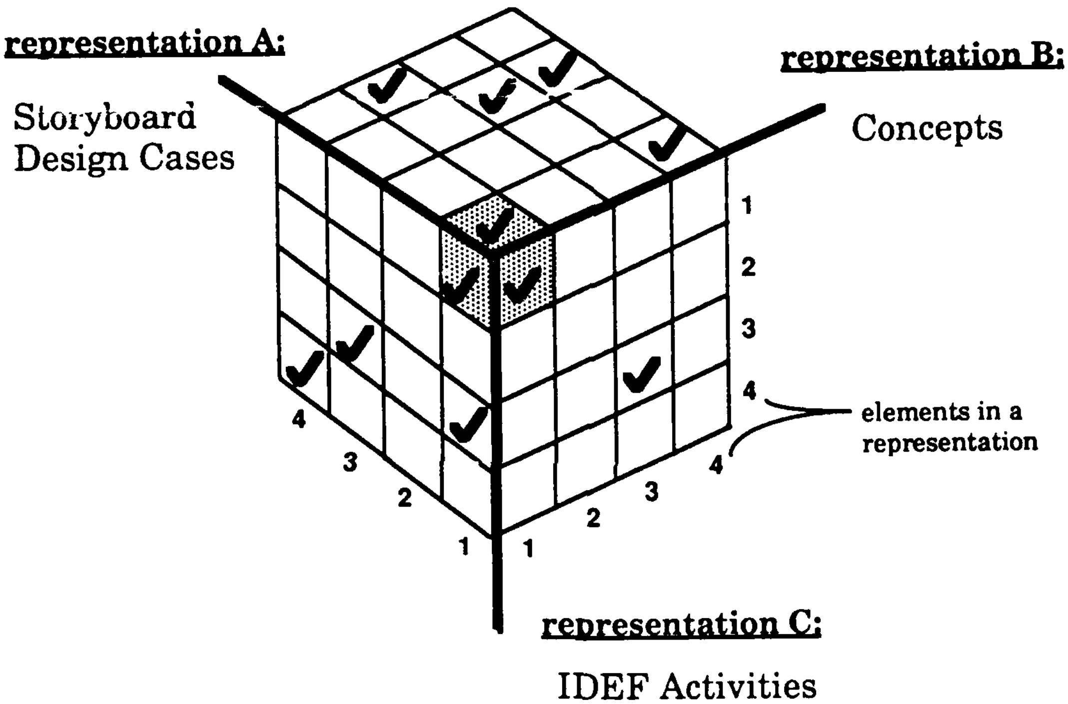


Figure 5-1 Integrative Structure

analysis, synthesis, research, and design opportunities. The cube shows the union of the three different types of knowledge representations acquired (e.g., storyboard design cases, concepts, and $IDEF_0$ activities). The check mark indicates the existence of a specific link between any two elements within a given knowledge representation (e.g., a check mark links element A4 and C4 as a partially integrated substructure). The cube that is illustrated in Figure 5-1 shows only four elements per knowledge representation for sake of example, but there may be as many elements as required in each representational scheme. For example, a concept map may have as many as 500 concepts or more, with each concept or cluster of concepts depicted as an element within the integrative structure.

One way to explain the integrative structure is to describe its various building blocks and the way that each block exists in a hierarchical relation with another block. Figure 5-2 lists these building blocks.

At the most global level, the overall knowledge space represents the union of the three knowledge representations. Second, each representation contains a number of specified elements (i.e., the concepts within a concept map, the activity boxes within an $IDEF_0$ diagram, or the design objects of a design storyboard). At a more local level, each element may consist of specific attributes. The attributes can be most easily understood with reference to the $IDEF_0$ model, in which the inputs, mechanisms, controls, and outputs associated with an activity box are the attributes of that element.

Because of the lack of predefined structure associated with the concept map, its attributes must be defined relatively. In other words, whether a concept is an element or an attribute of that element is likely to change as a function of the viewer's focus. The attributes of a concept are simply other concepts that qualify or serve to define the properties of the former concept. For example, if the key concept of a concept cluster has been defined as an element of the concept map, then the various concepts in the cluster could be regarded as the attributes of that key concept. However, any one of the various concepts in the cluster may also function as parent concept further defined by additional concepts. In this case, the parent concept would be regarded as the element with the child concepts being its attributes. Whenever the concept map undergoes a "rubber sheet" transformation, the

BUILDING BLOCKS

- Knowledge Space = $\cup$ { representations A, B, C }
- Representation A, B, C = $\cup$ { elements 1 to x }
- Elements x = $\cup$ {attributes within representations A, B, C }

-examples IDEF: inputs, mechanisms, controls, outputs
CM: clusters, relations, individual pilot maps, individual pilot interview tapes
Design Cases: frame, decision point-time sequence, design symbology, HF features

-special attributes: the IDEF$_0$ dictionary
the KEY CONCEPTs

Figure 5-2 Building Blocks for an Integrative Structure relative aspects of the attributes also change. Concepts which were once children may then be repositioned in the map as parents. Hence, the attribute structure changes accordingly. Consequently, the particular rubber sheet 'states' may act as attributes of relativity.

The attributes of a given design case also exist but, like the concept map attributes, the storyboard attributes are not as grammatically explicit as $IDEF_0$ attributes. The design objects within a storyboard frame are likely to be the elements with its attributes being such things as: the design symbology, the spatial-temporal locations, the required switchology, and the specific human factors engineering codification features (e.g. color, display luminance, and auditory signatures). Hence, all three types of knowledge representations are comprised of elements with various attributes composed in different formations.

5.3 Linkage Types

The integrative structure proposes three major types of linkages: simple, compound, and complex connections of entities (see Figure 5-3).

Simple linkages represent the intersections between two or more specifically defined elements (or attributes) of different knowledge representations. Simple linkages are further defined as having two different types of links, primary links and secondary links which are differentiated on the basis of whether they connect two or more elements (or attributes) that exist on the same level of granularity, or whether they connect elements (or attributes) that traverse different levels of granularity. The primary linkages represent the intersection of specifically defined elements (or attributes) from two or more knowledge representations that exist at comparable levels of granularity. For instance, a given concept of a map (e.g., "bomb fragmentation altitude") may be linked to a design storyboard element (e.g., the graphic depiction of the weapon delivery clock). The secondary links are those that connect elements or attributes that are at distinctly different levels of granularity within their respective knowledge representations. For example, the concept mapping knowledge

SIMPLE LINKAGES

primary links

- $\cap_1$ { x units of any 2 or more dimensions }

secondary links

- $\cap_2$ { x trace dimensions of any two or more dimensions

OR

- $\cap_3$ {x trace dimensions of any x unit(s) of a dimension

COMPOUND LINKAGES

- $\cap_4$ { 2 or more partial structures}

COMPLEX LINKAGES

- $\cap_5$ {2 or more fully integrated structures}
- $\cap_6$ {x partial structure(s) and x ull structure(s)

Figure 5-3 Linkage Types

representation element "situation awareness" might be linked to the $IDEF_0$ attribute, "navigation system malfunction status".

When simple linkages connect just two elements and/or attributes together, a partially integrated substructure is formed (see Figure 5-4). When simple linkages connect all three knowledge representations, then a fully integrated substructure is created (see Figure 5-5). The fully integrated substructure reflects a volume of the overall knowledge space and consists of the integration of three partial substructures (which reflect only a surface on the knowledge space). The formation of fully integrated substructures begins to signify the progressive deepening of knowledge.

The next major type of connection, compound linkages, consists of the intersection of two or more partial substructures that traverse levels of the hierarchical structure. This may signify the composition of knowledge from more basic levels to more generalized relationships. The compound linkage also takes an expansive view of complexity in that, by definition, the network of relationships is expanding. This may also be the basis for analogical renderings of acquired knowledge.

The last connection type, complex linkages, consists of the intersection of two or more integrated substructures, or the intersection of a partial substructure(s) with a full substructure(s). Like the compound links, complex links represent the most generalized and expansive forms of integration within the knowledge space. As several of these links get connected together, the basis for rule derivation, causality, and belief systems may be formed. Hence, it is evident that there are a number of different types of linkages possible within the integrative structure.

5.4 Evolution of the Integrative Knowledge Structure

The discussion of integrative structures has assumed that relations within a given representation have already been specified for that given representation. Within the $IDEF_0$ diagram, for example, there are already specified relations between attributes and the elements (e.g., how controls effect flow from input to output given a certain defined activity). However, as new users examine the integrative structure they may see additional

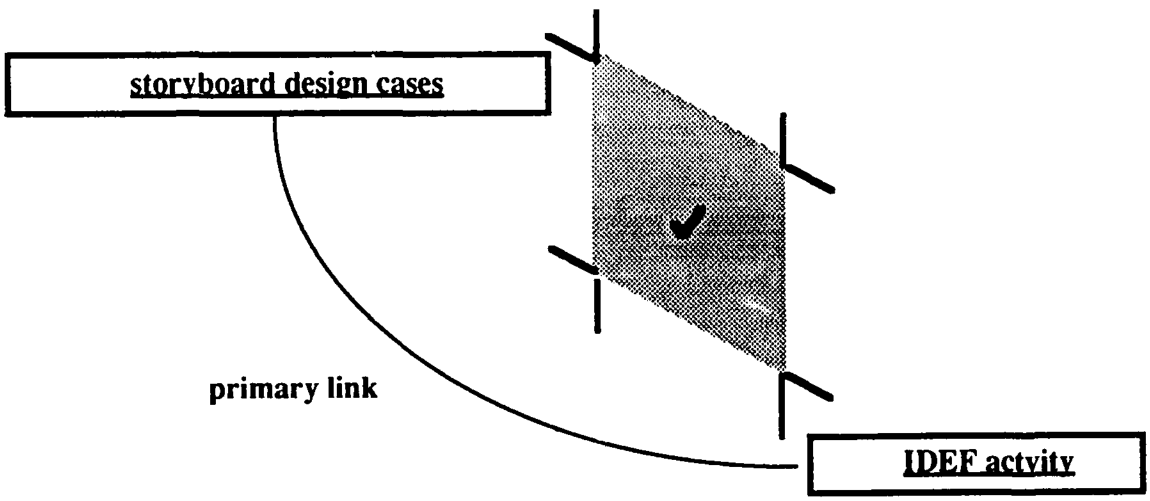


Figure 5-4 A Partially Integrated Substructure

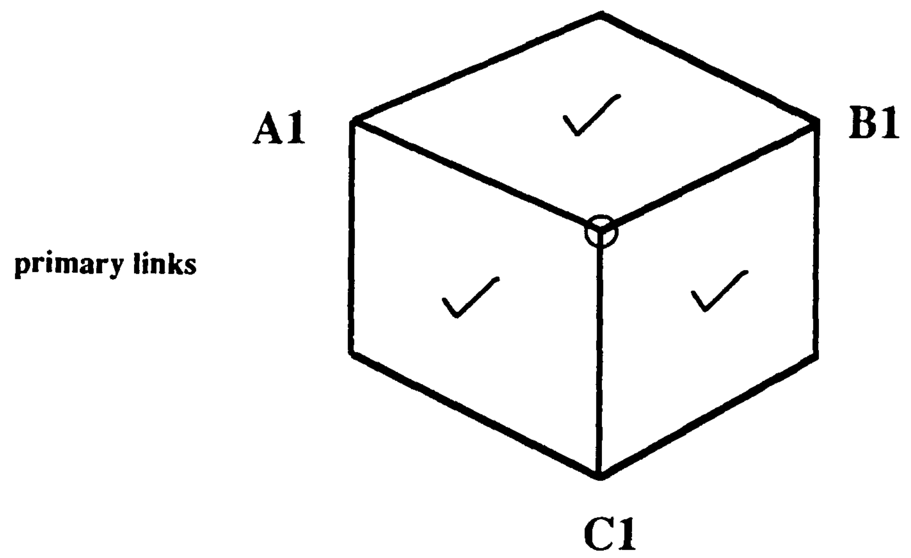


Figure 5-5 A Fully Integrated Substructure

within-representation relations which hitherto were not identified. The integrated structural utility will allow such within-dimension relations to be made as well, thereby facilitating the maturation of the individual representations of knowledge. It is also possible that by adding new associations, generative activity will occur which spawns entire new directions of knowledge/design. So if a user makes a linkage and it creates a major insight, the possibility for expansion of any view is facilitated. Hence the integrative structure exists as a possibility for further development.

This section has described the knowledge space, building blocks, and specific linkages which form the cornerstones of the integrative structure. What has not been elaborated is who makes the links? The design team members are the people who are entrusted with the job of establishing new linkages as a part of the knowledge and design acquisition process. Whenever a linkage is made within the domain of the integrative structure, it would be tagged as to the perspective of the individual design team member effecting the connection. Therefore, in addition to each knowledge representation being indicative of a different perspective, any changes to these models or links among these models will also be traceable to a particular individual's perspective (i.e., designer, pilot, human factors engineer, etc.).

The intention for 'link production' is to have the same pilots whose knowledge is embodied in the current representations establish the initial linkages between those various representations. In this way, the pilots would be making links among entities which in fact they generated in their earlier sections. An observation during the storyboard session revealed that the pilots were quite comfortable moving back and forth between the concept maps and the design storyboards and establishing the connections between these two knowledge representations. We found that as pilots began to design their storyboards they also would talk about concepts and functions required.

The set of baseline simple linkages would represent the first order of growth within the integrative structure. As the integrative structure is viewed from the different perspectives, the level of learning and the amount of knowledge progressively deepens to yield more complex relationships.

The formation of multiple integrated substructures within the knowledge space signals that substantial learning and integration is taking place as the different models of knowledge (which were initially disparate and isolated) become inter-related and usable for future knowledge and design acquisition activities. In essence, the integrative structure takes the 'mental models' of many and explicitly provides them to others to look at, learn from, adapt, and decimate if need be. The vision of what the PA must consist of, what it produces, and how it works are a function of knowing how pilots think about, design, and use current cockpit technology, obtaining their ideas on where weaknesses are, and seeking their vision as to what information/functions they require. As a consequence, the development of the PA is in direct association with the pilot such that the pilot drives the design rather than having the pilot serve the technology.

6.0 SUMMARY AND CONCLUSION

The identification of aircraft system requirements has traditionally been accomplished during the initial phases of the engineering design process. To a large degree these requirements are influenced by the designer's experience level and ability, and are driven by technical constraints that result from the various hardware and software limitations and capabilities. This process all too frequently results in a mismatch between what the pilots need, and what the engineers designed (Norman, 1988; Zaff, 1989). The elimination of resulting discrepancies typically requires a time consuming and expensive process of iterative redesign and refinement based on pilot testing and critique. In order to facilitate the design of a system that more closely matches the needs, capabilities and desires of the user, we have advocated an approach to system design and development that attempts to fuse together the disparate perspectives of user requirements arising from the system analyst's conception of the requirements, the designer's conception of the requirements, and user's conception of the requirements. In order to accomplish this goal, we have set out to investigate the requirements definition process from all three perspectives, and to capture the requirements with an integrated set of knowledge and design acquisition techniques that facilitate graphical knowledge representation and iterative design.

The efforts to develop a knowledge and design acquisition methodology has placed great emphasis on obtaining information from pilots to demonstrate the utility for capturing the pilots' perspective on the mission requirements. The methodology appears to be capable of providing the eventual large-scale knowledge base which has been envisioned for the Pilot's Associate. For this reason, the integrated knowledge and design acquisition process gave the pilots the opportunity to be placed in the roles of mentor, analyst, and designer. It also placed knowledge engineers in the role of 'apprentices' to the pilots. This was a unique utilization of the pilots' knowledge in the design process, as normally they are only asked for their opinions during a cursory review of the design prototypes.

Finally, the vision of transforming knowledge as design has been demonstrated as an innovative, productive, and viable goal for acquiring, assimilating, and representing knowledge within the application of the Pilot's Associate. The manifestation of knowledge as design facilitates the realization that pilots can in fact be integral in the development of a cooperative knowledge based system proposed to be their 'associate'.

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APPENDIX A

CONCEPT MAPS

Concept Map Legend

Segmented Concept Map 1[1]

pg. 108	pg. 109	pg. 110	pg. 111
pg. 112	pg. 113	pg. 114	pg. 115
pg. 116	pg. 117	pg. 118	pg. 119

Complete Concept Map 1

pg. 107

Segmented Concept Map 2

pg. 121	pg. 122
pg. 123	pg. 124

Complete Concept Map 2

pg. 120

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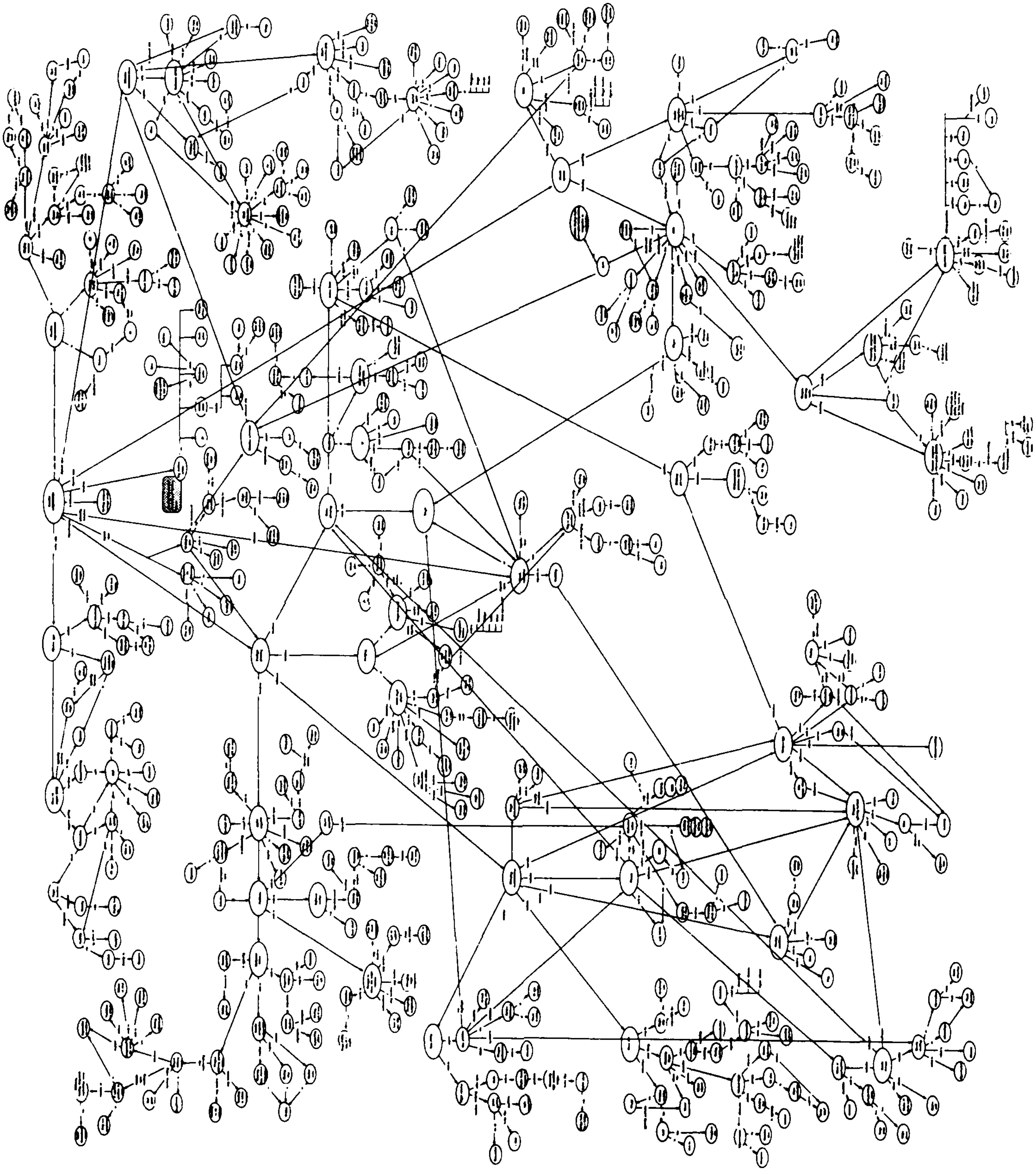
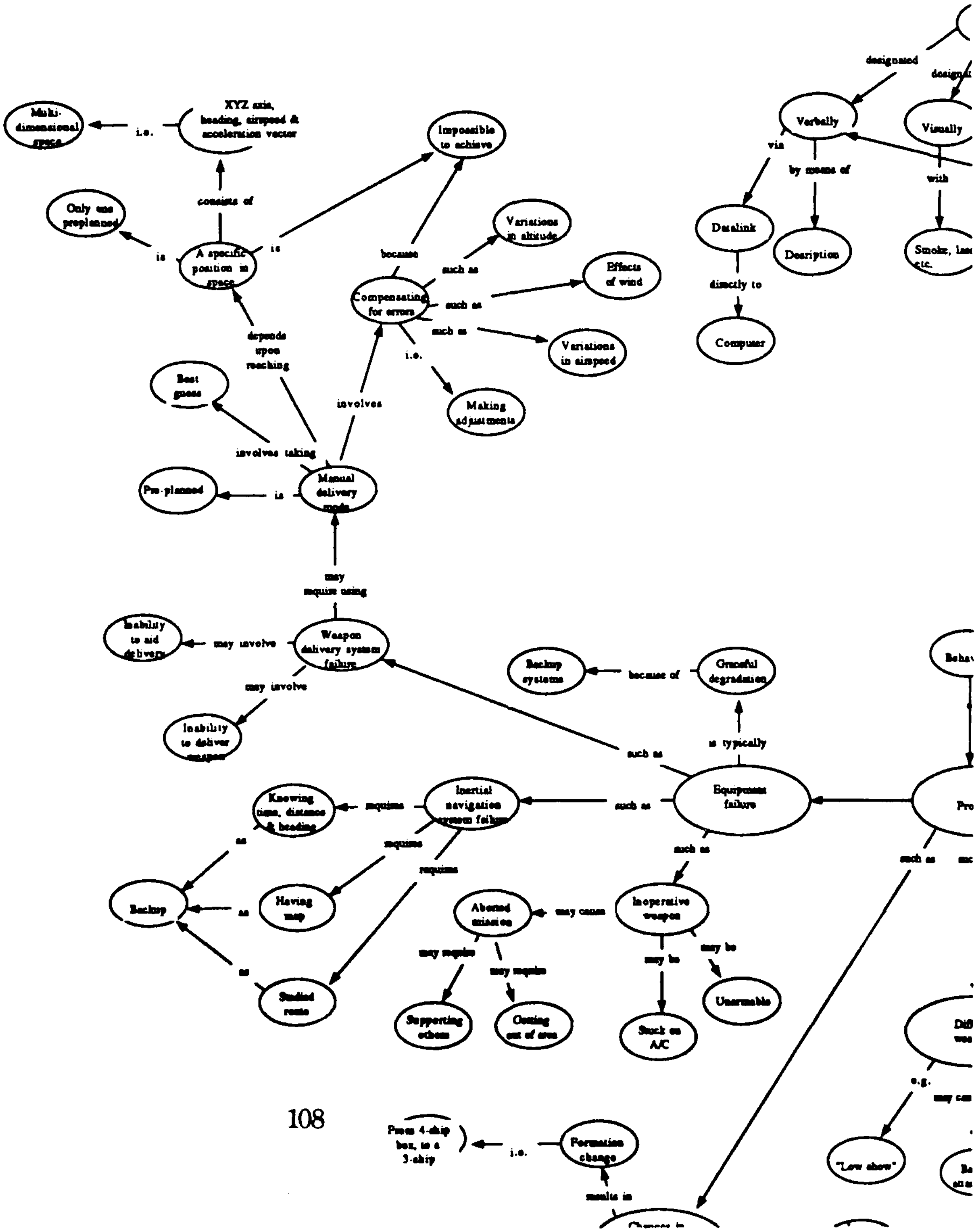
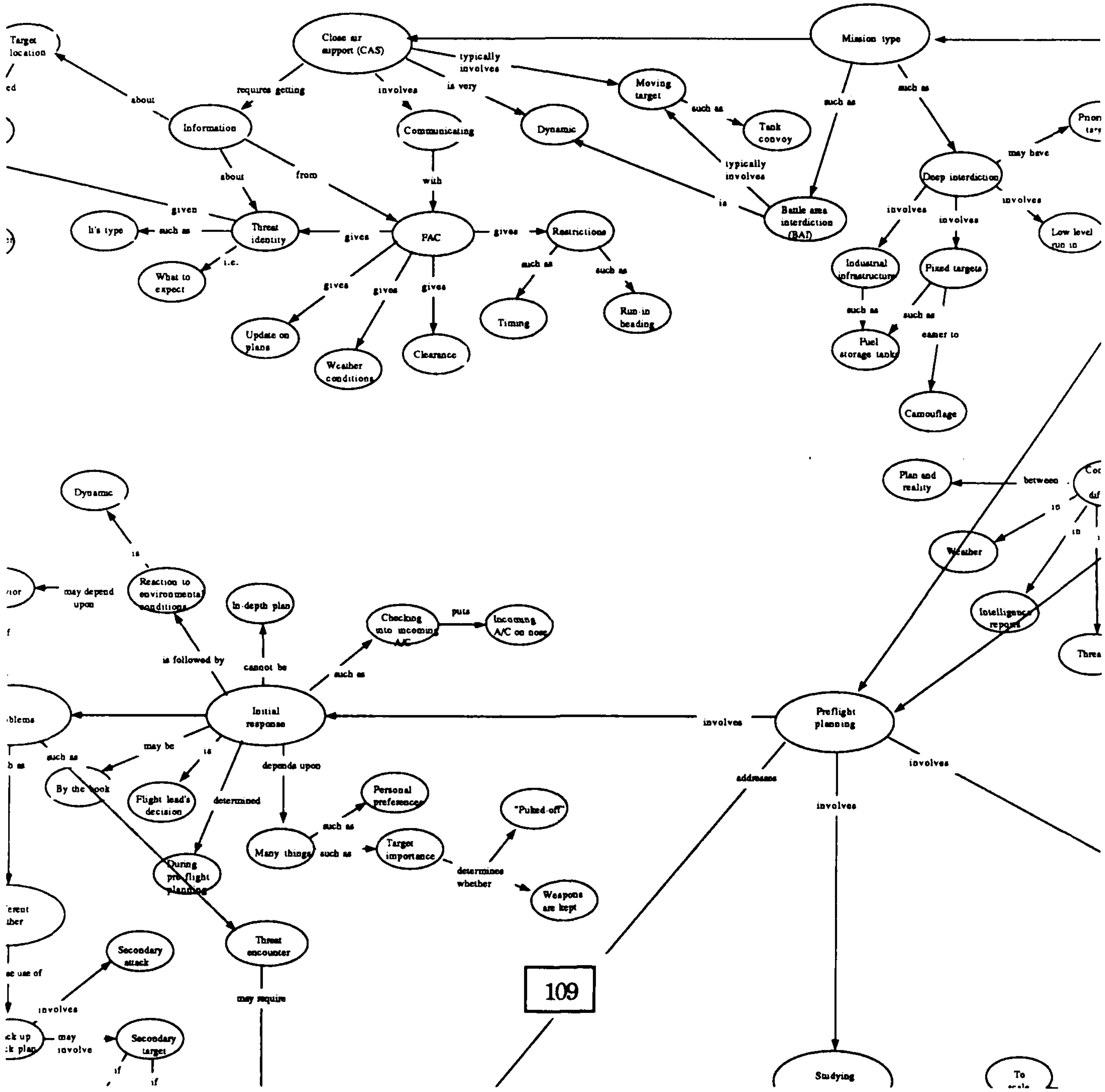
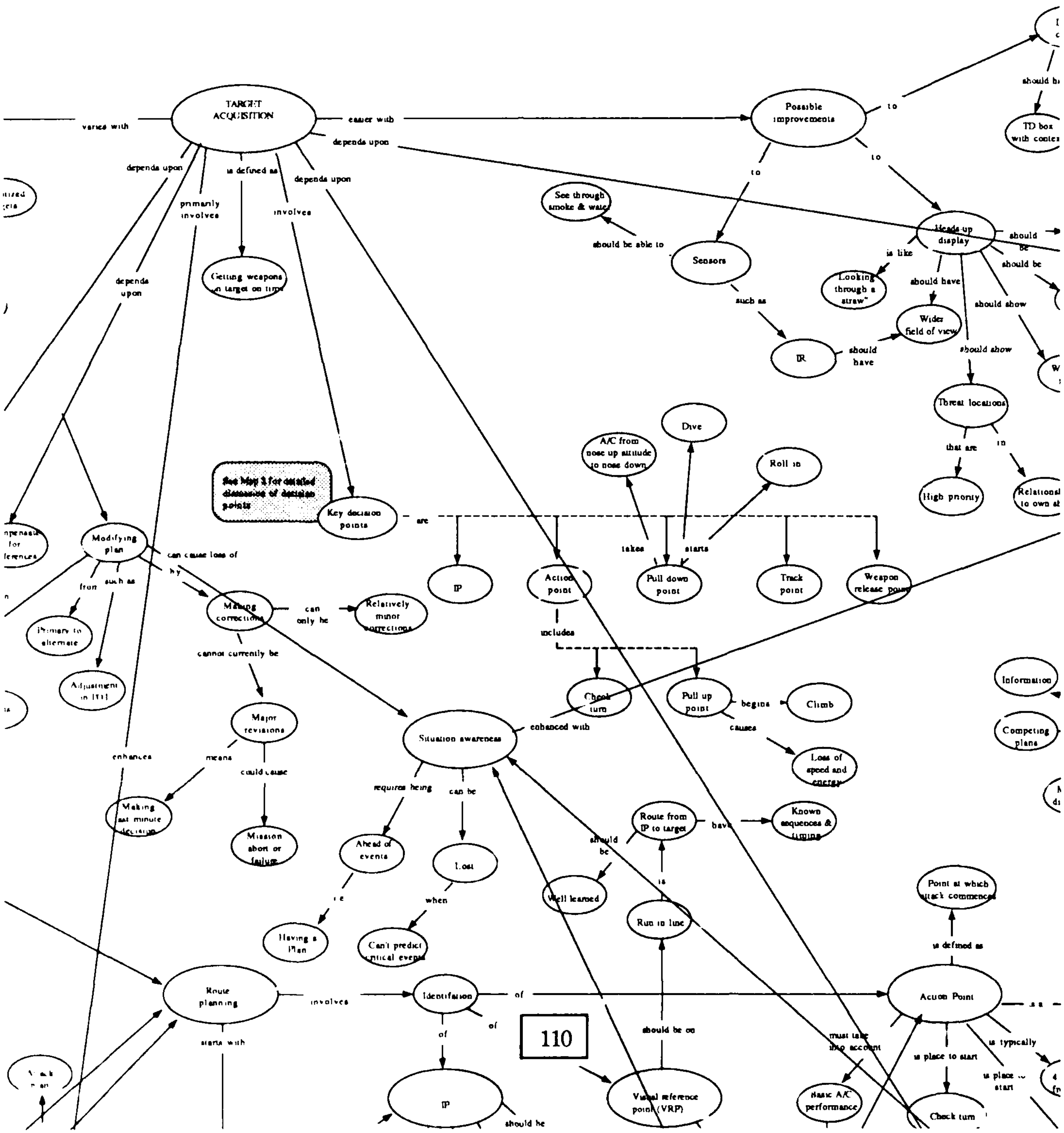
1 In practice the concept maps are viewed on a single continuous sheet of paper. Printing restrictions have prevented its presentation in this more desirerable format.

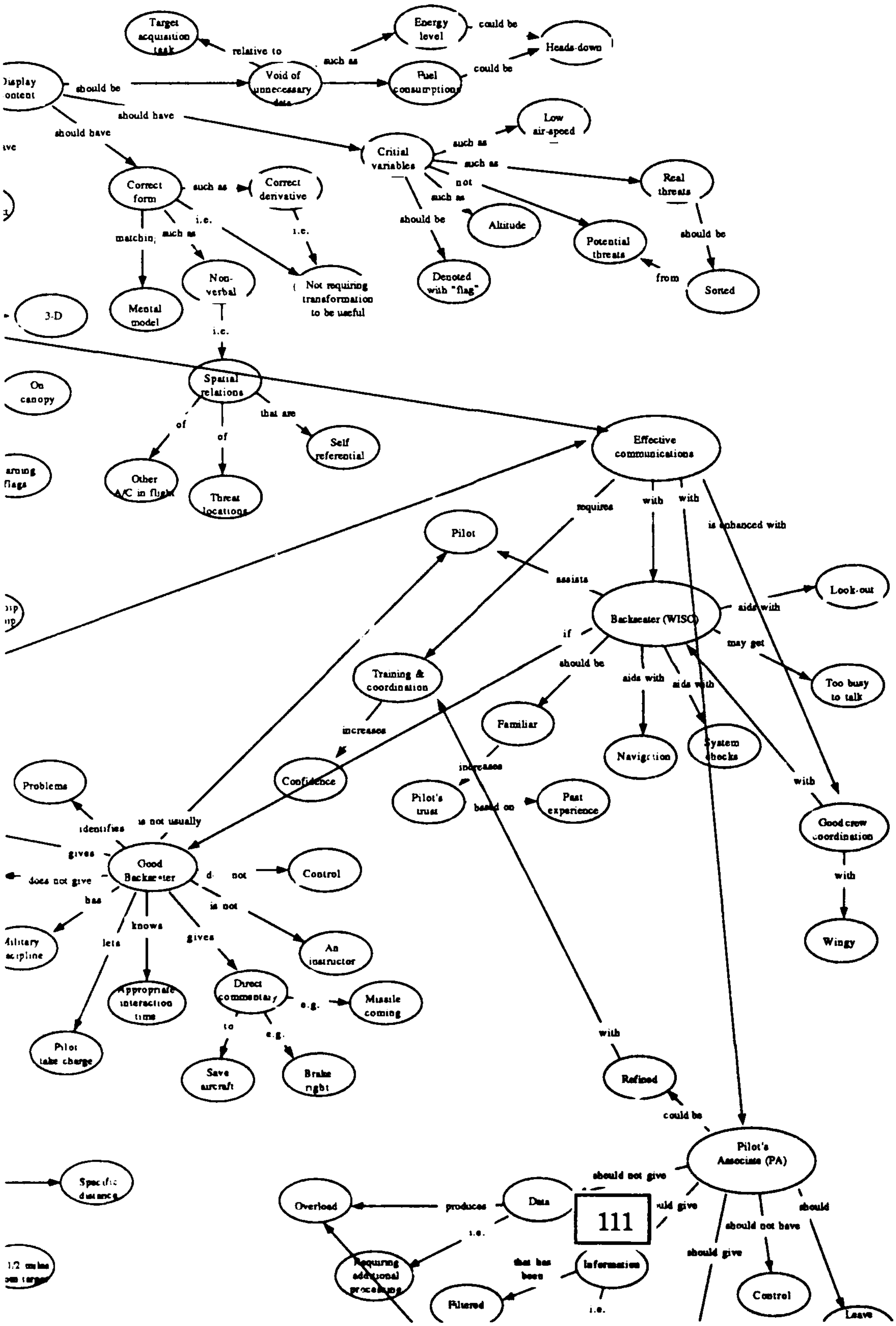



designated
Verbally
Visually
via
by means of
with
Datalink
Description
Smoke, lase etc.
directly to
Computer
Multi-dimensional space
i.e.
XYZ axis, heading, airspeed & acceleration vector
Impossible to achieve
consists of
Only one preplanned
is
A specific position in space
is
because
Variations in altitude
such as
Compensating for errors
such as
Effects of wind
such as
Variations in airspeed
i.e.
Making adjustments
depends upon reaching
involves
Best guess
involves taking
Pre-planned
is
Manual delivery mode
may require using
Inability to aid delivery
may involve
Weapon delivery system failure
may involve
Inability to deliver weapon
Backup systems
because of
Graceful degradation
is typically
such as
Knowing time, distance & heading
requires
Inertial navigation system failure
such as
Equipment failure
requires
requires
as
Backup
as
Having map
as
Studied route
Aborted mission
may cause
Inoperative weapon
such as
may require
may require
may be
may be
Supporting others
Getting out of area
Stuck on A/C
Unarmable
such as
e.g.
"Low show"
From 4-ship box, to a 3-ship
i.e.
Formation change
results in
Changes in

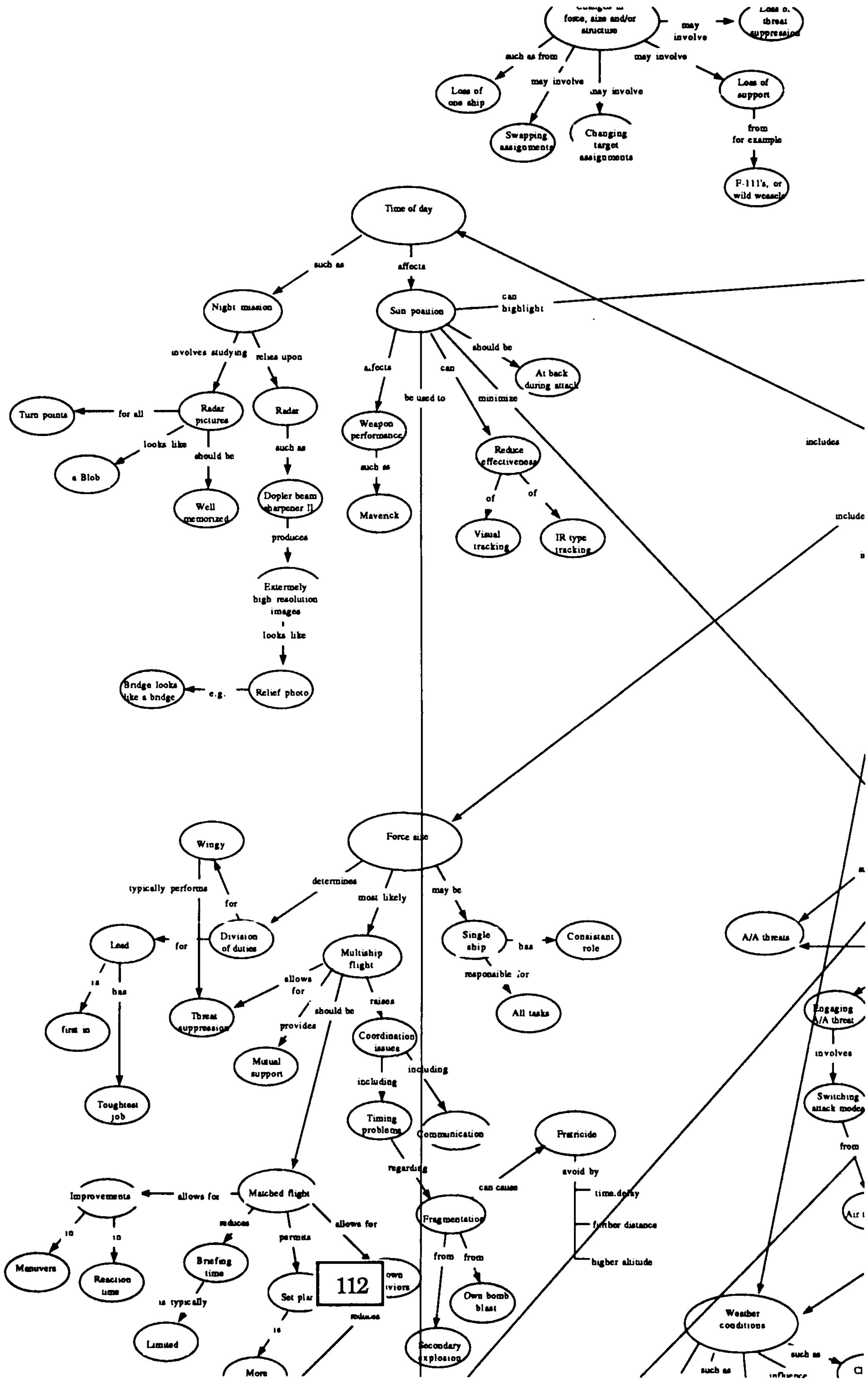

Close air support (CAS)
Mission type
typically involves
Moving target
such as
Tank convoy
requires getting
involves
is very
Dynamic
such as
such as
Information
about
Target location
Communicating
with
typically involves
Deep interdiction
may have
involves
involves
involves
is
Battle area interdiction (BAI)
about
from
given
It's type
such as
Threat identity
gives
FAC
gives
Restrictions
i.e.
What to expect
gives
gives
gives
such as
such as
Update on plans
Weather conditions
Clearance
Timing
Run-in heading
Low level run in
Industrial infrastructure
Fixed targets
such as
such as
easier to
Fuel storage tanks
Camouflage
Plan and reality
between
Weather
Intelligence reports
Dynamic
is
may depend upon
Reaction to environmental conditions
In-depth plan
Checking into incoming A/C
puts
Incoming A/C on nose
is followed by
cannot be
such as
Initial response
involves
Preflight planning
such as
may be
is
By the book
Flight lead's decision
determined
depends upon
Personal preferences
such as
Many things
such as
Target importance
"Puked-off"
determines whether
Weapons are kept
During pre-flight planning
Threat encounter
may require
addresses
involves
involves
Secondary attack
involves
may involve
Secondary target
Studying



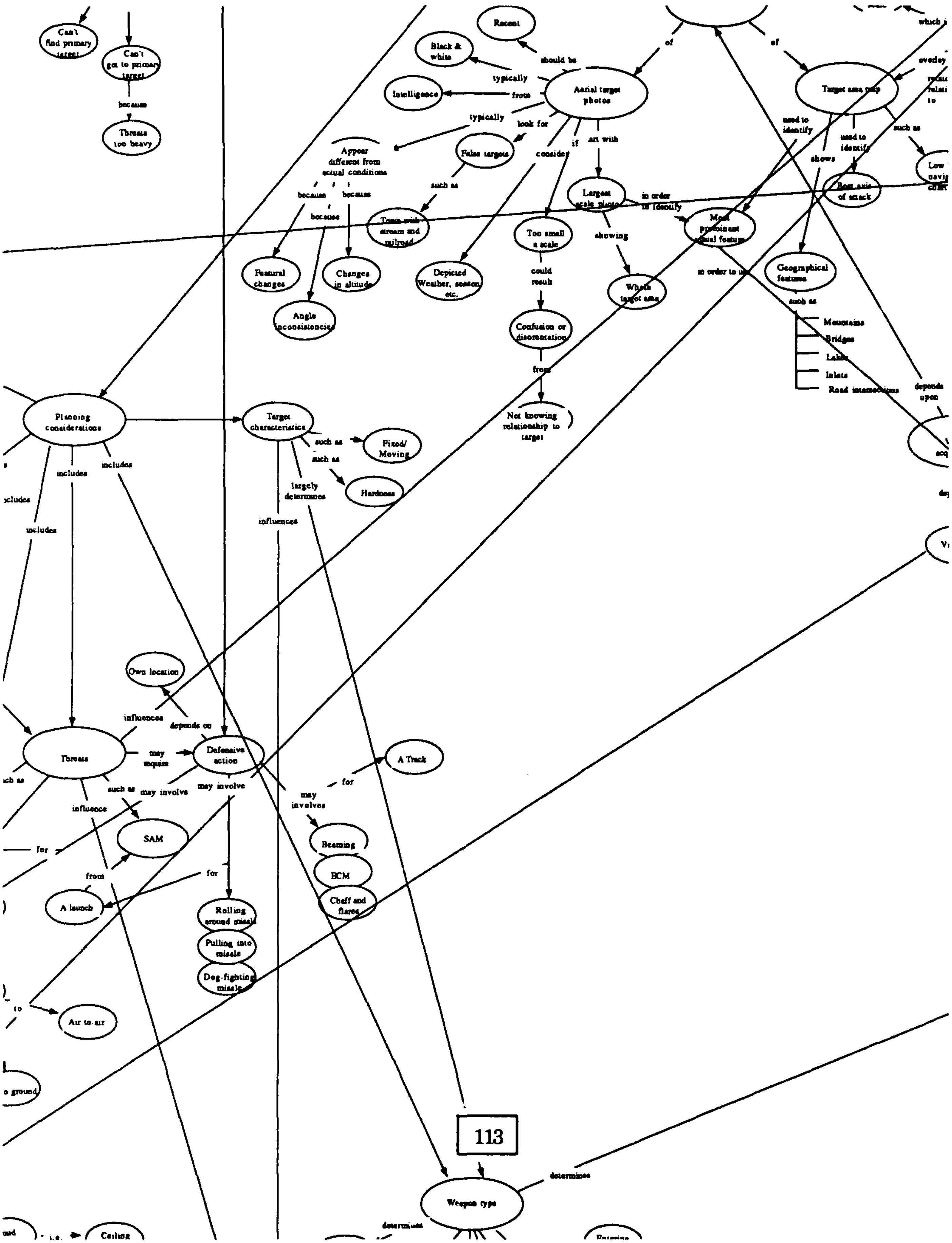
TARGET ACQUISITION
varies with
easier with
depends upon
is defined as
primarily involves
involves
Getting weapons on target on time
Possible improvements
to
Sensors
should be able to
See through smoke & water
such as
IR
should have
Wider field of view
Heads up display
is like
"Looking through a straw"
should have
should show
should be
Threat locations
that are
High priority
Relationship to own a/c
TD box with context
See Map 3 for detailed discussion of decision points
Key decision points
are
IP
Action point
Pull down point
Track point
Weapon release point
A/C from nose up attitude to nose down
Dive
Roll in
takes
starts
includes
Check turn
Pull up point
begins
Climb
causes
Loss of speed and energy
Modifying plan
can cause loss of
from
such as
Primary to alternate
Adjustment in TOT
by
Making corrections
can only be
Relatively minor corrections
cannot currently be
Major revisions
means
could cause
Making last minute decision
Mission abort or failure
enhances
Situation awareness
enhanced with
requires being
can be
Ahead of events
Lost
Having a Plan
when
Can't predict critical events
Route from IP to target
have
Known sequences & timing
should be
Well learned
is
Run in line
Route planning
involves
starts with
Identification
of
should be on
Visual reference point (VRP)
should be
Information
Competing plans
Point at which attack commences
is defined as
Action Point
must take into account
Basic A/C performance
is place to start
is typically
Check turn

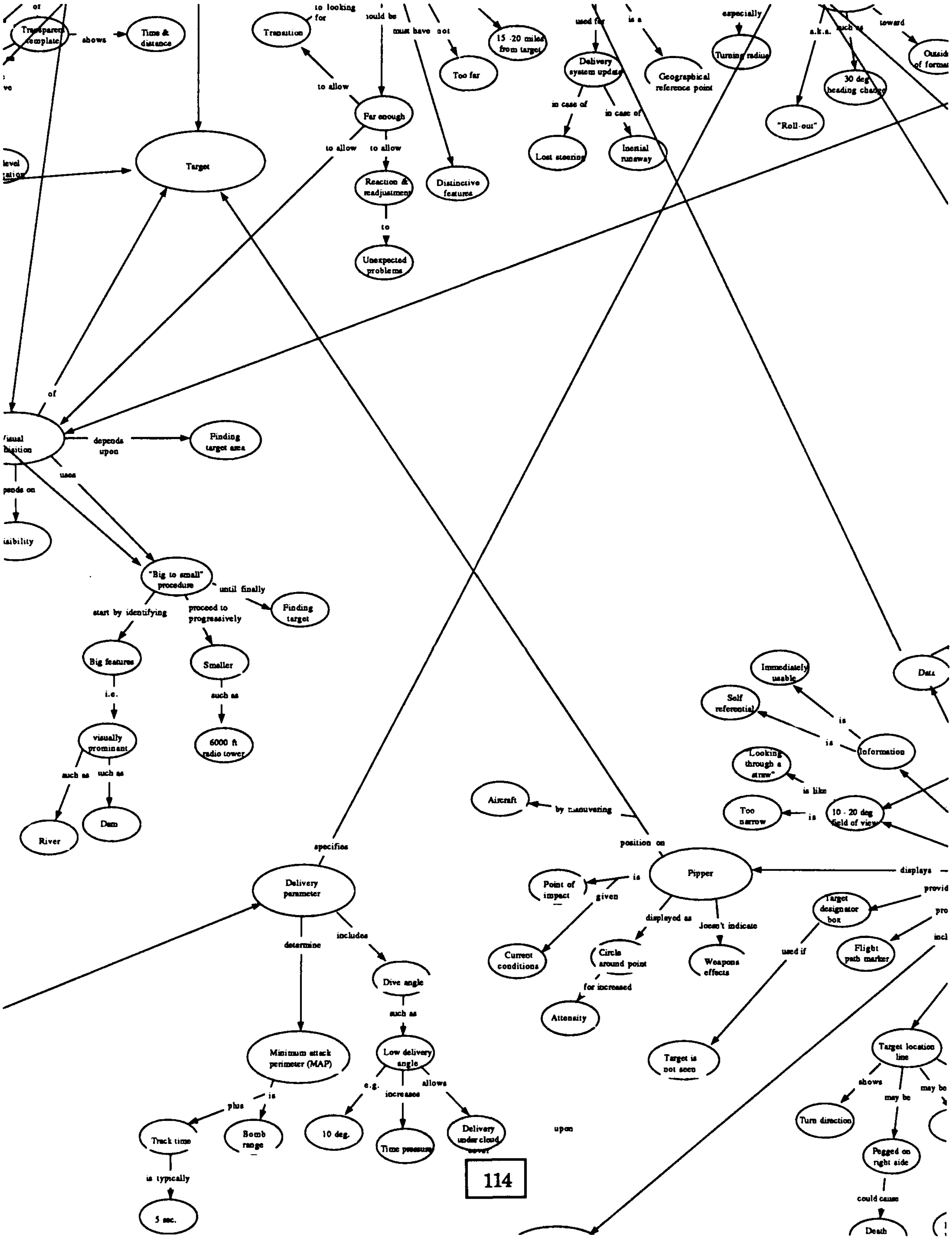


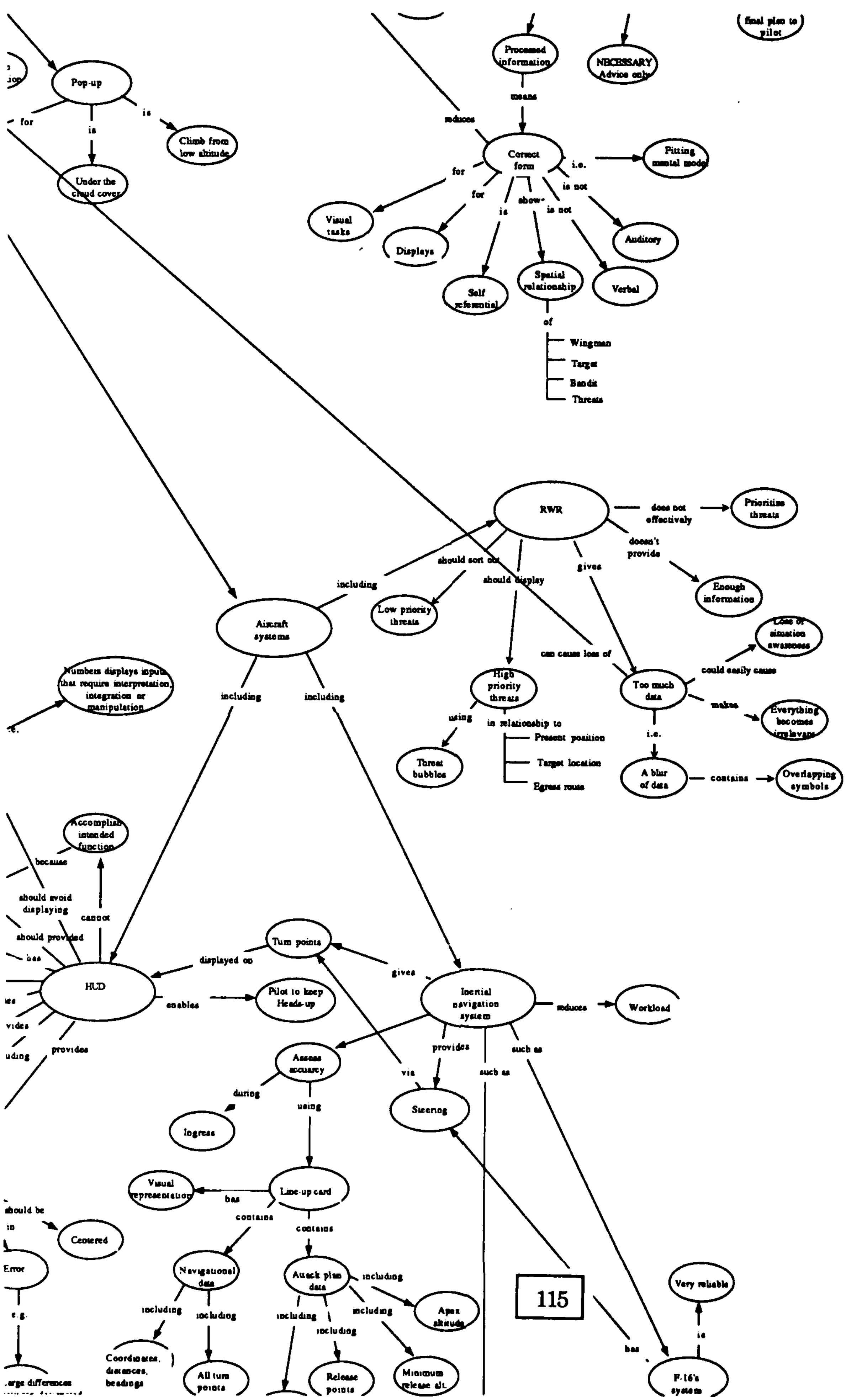
Target acquisition task
relative to
Energy level
could be
Heads-down
such as
Void of unnecessary data
Fuel consumption
could be
Display content
should be
should have
should have
Low air-speed
Critial variables
such as
such as
Real threats
Correct form
such as
Correct derivative
not
such as
i.e.
i.e.
should be
Altitude
should be
matching
such as
Potential threats
Non-verbal
Not requiring transformation to be useful
Denoted with "flag"
from
Sorted
Mental model
3-D
i.e.
Spatial relations
On canopy
of
of
that are
Self referential
Effective communications
Other A/C in flight
Threat locations
requires
with
with
is enhanced with
Pilot
assists
Look-out
Backseater (WISO)
aids with
if
should be
may get
Training & coordination
aids with
aids with
Too busy to talk
Familiar
increases
Navigation
System checks
increases
with
Problems
Confidence
Pilot's trust
based on
Past experience
Good crew coordination
identifies
is not usually
gives
Good Backseater
does not
Control
does not give
with
has
is not
knows
gives
lets
An instructor
Wingy
Military discipline
Appropriate interaction time
Direct commentary
e.g.
Missile coming
to
e.g.
Pilot take charge
Save aircraft
Brake right
with
Refined
could be
Pilot's Associate (PA)
Specific distance
should not give
Overload
produces
Data
should give
should
i.e.
should not have
Requiring additional processing
that has been
Information
should give
Control
Filtered
i.e.
Leave
1/2 miles from target



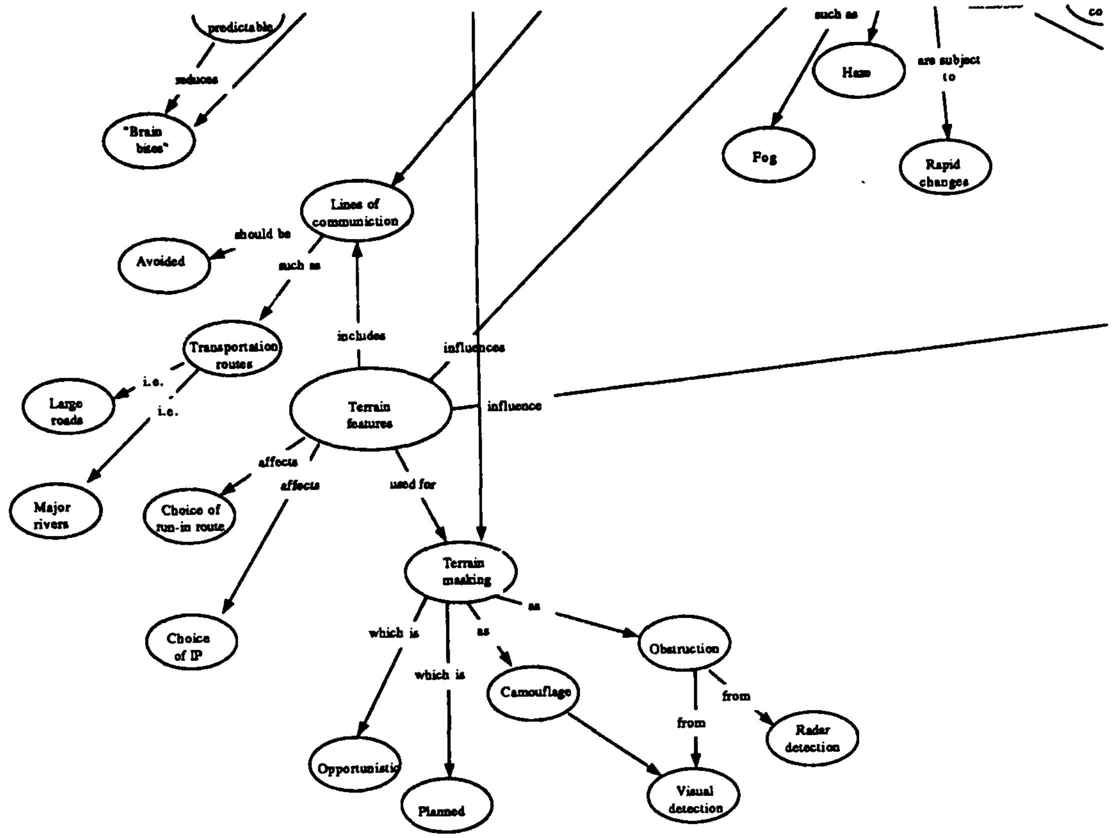
force, size and/or structure
may involve
threat suppression
such as from
Loss of one ship
may involve
may involve
may involve
Loss of support
Swapping assignments
Changing target assignments
from for example
F-111's, or wild weasels
Time of day
such as
affects
Night mission
Sun position
can highlight
involves studying
relies upon
should be
At back during attack
affects
can
be used to
minimize
Turn points
for all
Radar pictures
Radar
looks like
should be
such as
Weapon performance
Reduce effectiveness
includes
a Blob
Well memorized
Dopler beam sharpener II
such as
Maverick
of
of
Visual tracking
IR type tracking
produces
Extermely high resolution images
looks like
Bridge looks like a bridge
e.g.
Relief photo
Wingy
Force size
typically performs
for
determines
most likely
may be
Lead
for
Division of duties
Multiship flight
Single ship
has
Consistant role
A/A threats
is
has
allows for
should be
raises
responsible for
first in
Threat suppression
provides
Coordination issues
All tasks
Engaging A/A threat
Mutual support
including
including
involves
Toughest job
Timing problems
Communication
Fratricide
Switching attack modes
regarding
can cause
avoid by
from
time delay
Improvements
allows for
Matched flight
Fragmentation
further distance
reduces
permits
allows for
higher altitude
in
in
from
from
Menuvers
Reaction time
Briefing time
Set plan
Own bomb blast
is typically
reduces
Limited
Weather conditions
is
Secondary explosion
such as
More
such as
influence


Can't find primary target
Can't get to primary target
because
Threats too heavy
Recent
Black & white
should be
typically
Intelligence
from
Aerial target photos
of
Target area map
typically
look for
Appear different from actual conditions
False targets
if
consider
art with
used to identify
shows
such as
because
because
because
such as
Town with stream and railroad
Largest scale photos
in order to identify
Most prominent visual feature
Best axis of attack
Featural changes
Changes in altitude
Angle inconsistencies
Depicted Weather, season, etc.
Too small a scale
could result
showing
Whole target area
in order to use
Geographical features
such as
Mountains
Bridges
Lakes
Inlets
Road intersections
depends upon
Confusion or disorientation
from
Not knowing relationship to target
Planning considerations
Target characteristics
such as
Fixed/Moving
such as
Hardness
includes
includes
includes
largely determines
influences
Own location
influences
depends on
Threats
may require
Defensive action
A Track
for
such as
may involve
may involve
may involves
influence
SAM
Beaming
ECM
Chaff and flares
for
from
for
A launch
Rolling around missile
Pulling into missile
Dog-fighting missile
to
Air to-air
Weapon type
determines
determines
Ceiling

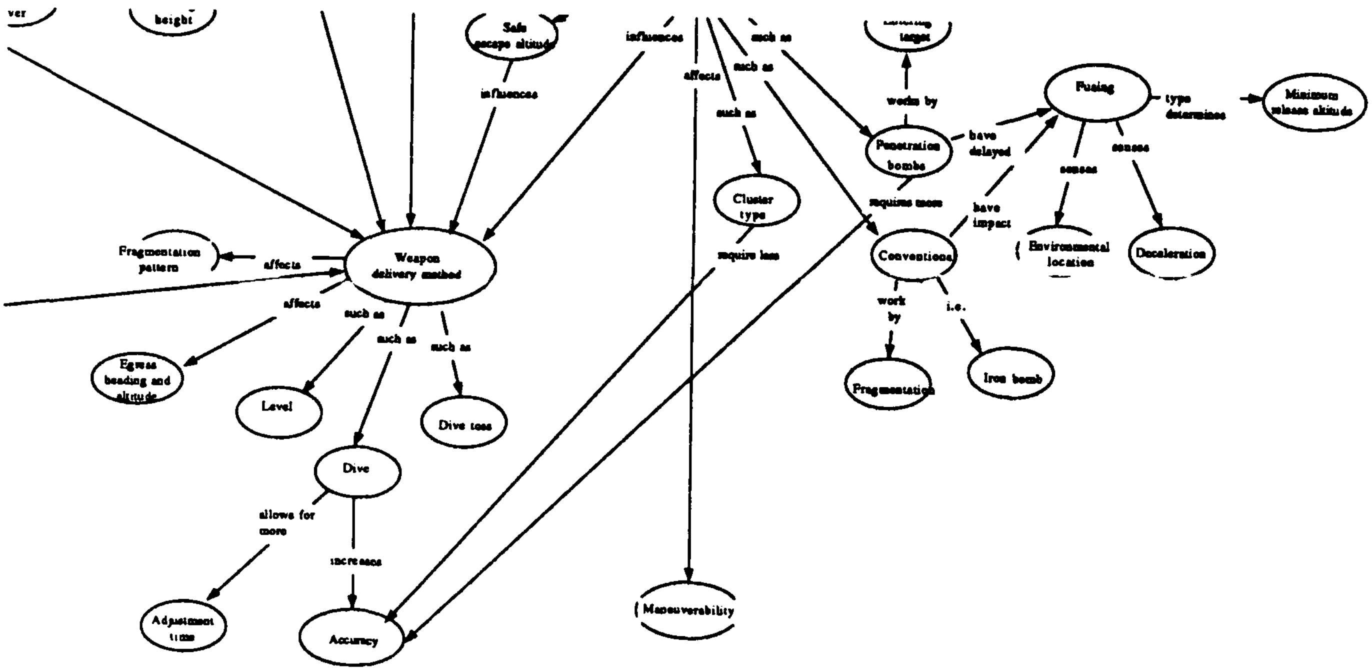

Transparent template
shows
Time & distance
Transition
to looking for
to allow
Far enough
must have
not
15 -20 miles from target
Too far
to allow
Reaction & readjustment
to
Unexpected problems
Distinctive features
Target
used for
Delivery system update
in case of
Lost steering
Inertial runaway
is a
Geographical reference point
especially
Turning radius
a.k.a.
"Roll-out"
such as
30 deg heading change
toward
of
Visual acquisition
depends upon
Finding target area
uses
Visibility
"Big to small" procedure
until finally
Finding target
start by identifying
Big features
i.e.
visually prominant
such as
River
Dam
proceed to progressively
Smaller
such as
6000 ft radio tower
Immediately usable
Self referential
is
Information
"Looking through a straw"
is like
10 - 20 deg field of view
Too narrow
Data
Aircraft
by maneuvering
position on
Pipper
displays
is
Point of impact
given
Current conditions
displayed as
Circle around point
for increased
Attensity
Doesn't indicate
Weapons effects
Target designator box
used if
Target is not seen
Flight path marker
Target location line
shows
Turn direction
may be
Pegged on right side
could cause
Death
specifies
Delivery parameter
determine
Minimum attack perimeter (MAP)
is
plus
Track time
is typically
5 sec.
Bomb range
includes
Dive angle
such as
Low delivery angle
e.g.
10 deg.
increases
Time pressure
allows
Delivery under cloud cover
upon

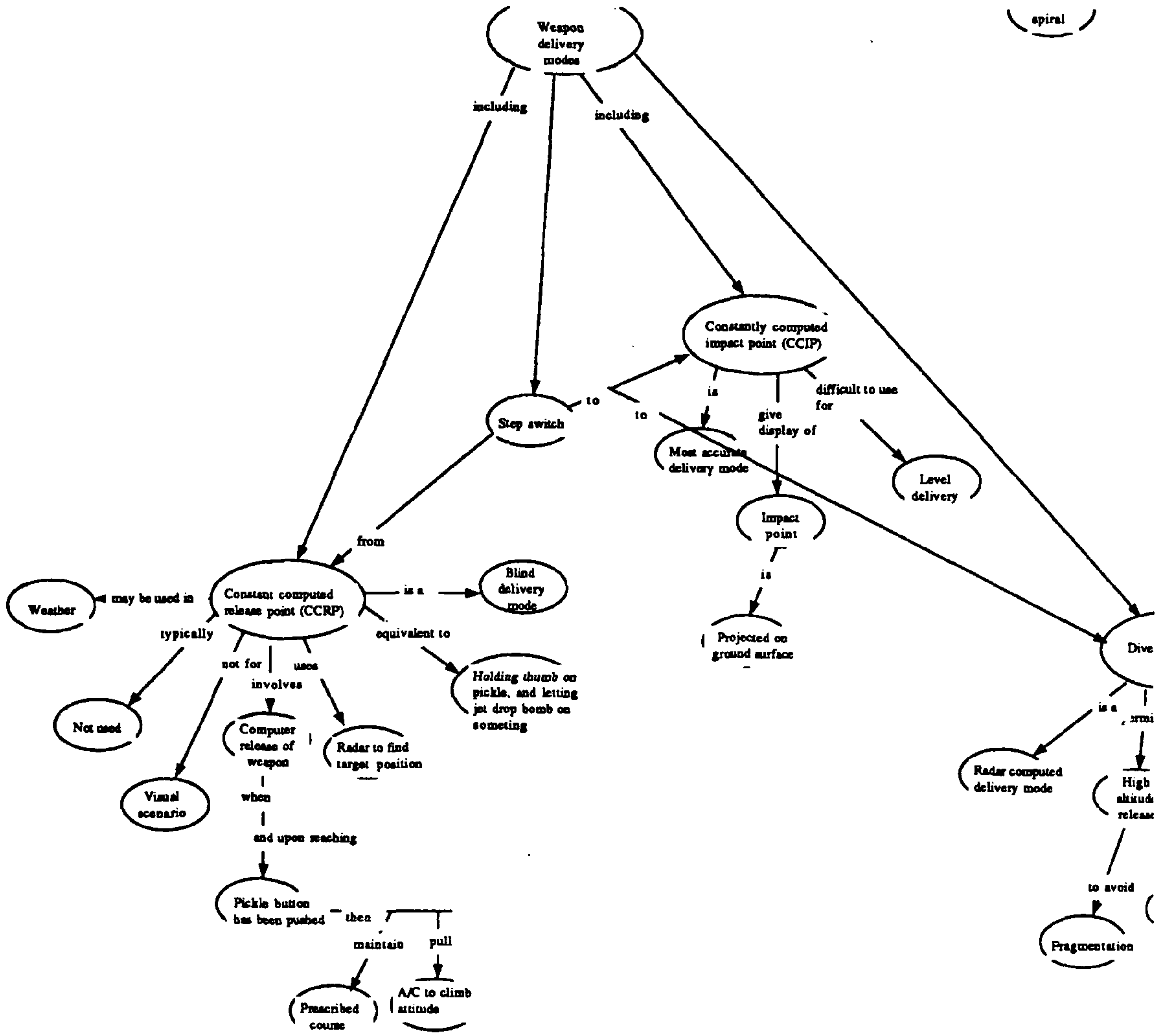


Pop-up
for
is
Climb from low altitude
Under the cloud cover
Processed information
NECESSARY Advice only
final plan to pilot
means
reduces
Correct form
i.e.
Fitting mental model
for
Visual tasks
Displays
is
Self referential
shows
Spatial relationship
of
Wingman
Target
Bandit
Threats
is not
Verbal
Auditory
RWR
does not effectively
Prioritize threats
doesn't provide
Enough information
gives
should sort out
Low priority threats
should display
High priority threats
using
Threat bubbles
in relationship to
Present position
Target location
Egress route
can cause loss of
Too much data
could easily cause
Loss of situation awareness
makes
Everything becomes irrelevant
A blur of data
contains
Overlapping symbols
including
Aircraft systems
Numbers displays inputs that require interpretation, integration or manipulation
Accomplish intended function
because
should avoid displaying
cannot
should provided
has
HUD
displayed on
Turn points
gives
Inertial navigation system
enables
Pilot to keep Heads-up
reduces
Workload
provides
Steering
via
such as
Assess accuracy
during
Ingress
using
Line-up card
has
Visual representation
contains
Navigational data
Attack plan data
including
Coordinates, distances, headings
All turn points
Release points
Minimum release alt.
Apex altitude
should be
Centered
Error
e.g.
Large differences
F-16's system
Very reliable

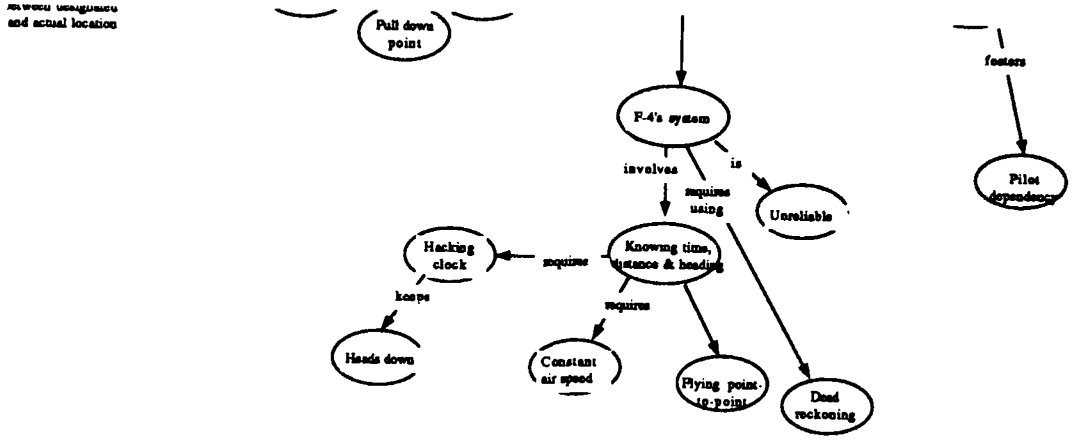


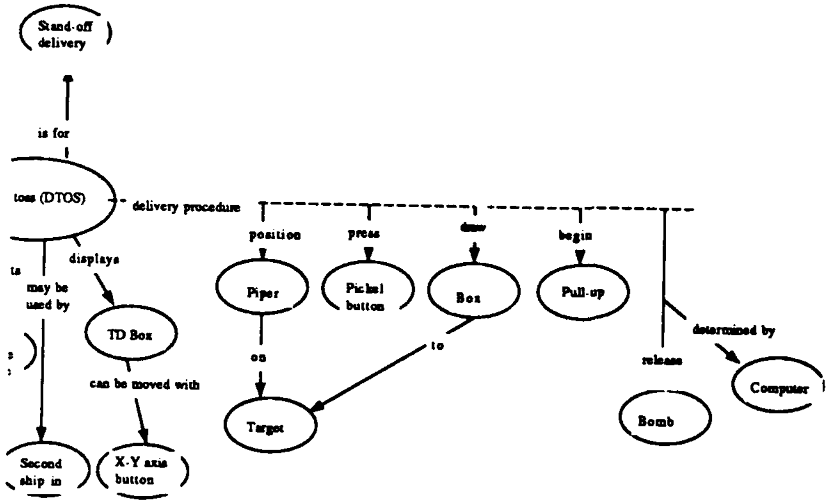
predictable
reduces
"Brain bites"
such as
Haze
are subject to
Fog
Rapid changes
Lines of communiction
should be
Avoided
such as
Transportation routes
includes
influences
i.e.
Large roads
i.e.
Terrain features
influence
Major rivers
affects
affects
Choice of run-in route
used for
Terrain masking
Choice of IP
as
which is
as
Obstruction
which is
Camouflage
from
from
Radar detection
Opportunistic
Planned
Visual detection

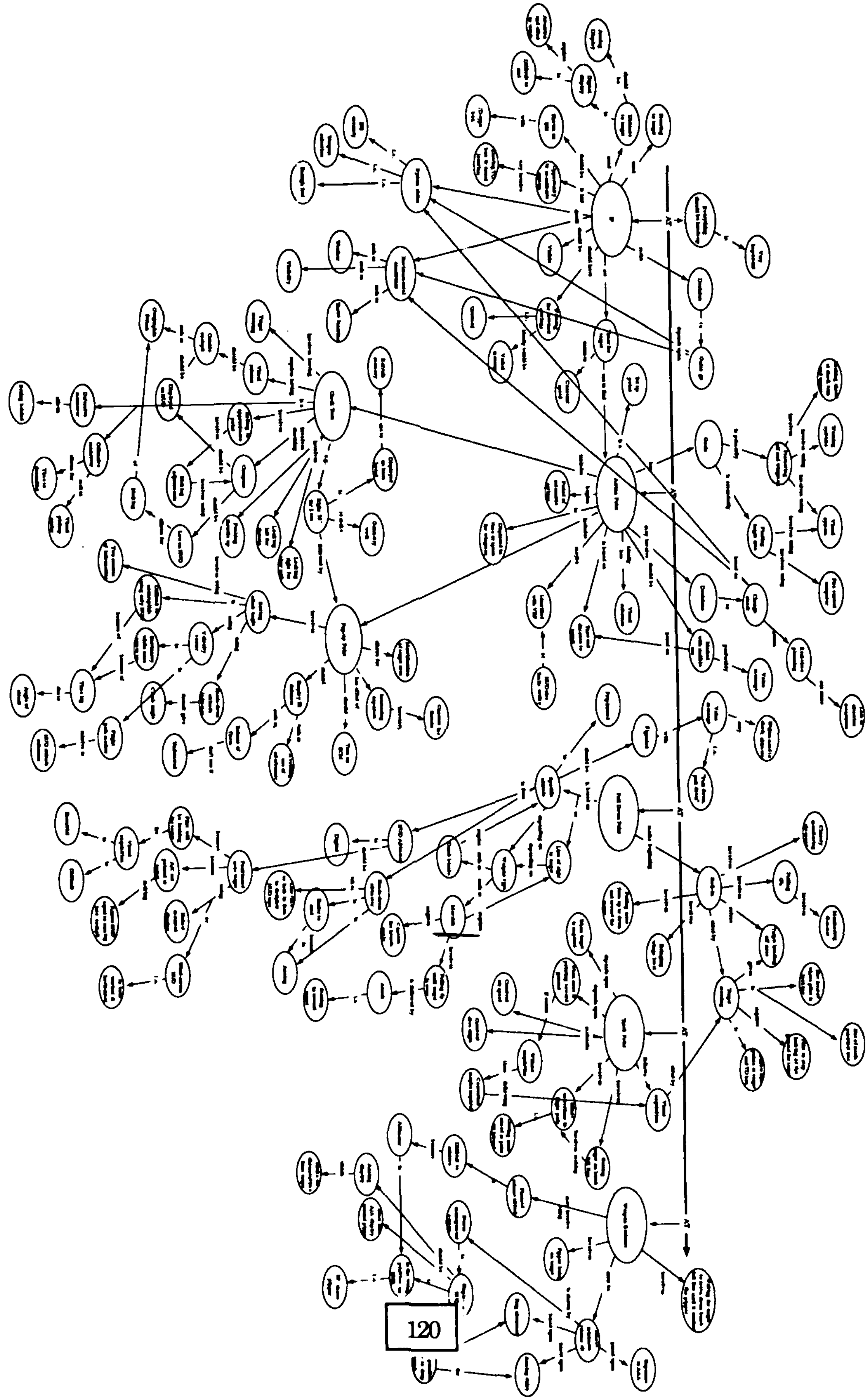

height
Safe escape altitude
influences
influences
affects
such as
such as
such as
target
works by
Fusing
type determines
Minimum release altitude
Penetration bombs
have delayed
senses
senses
Cluster type
requires more
have impact
Fragmentation pattern
affects
Weapon delivery method
Conventional
Environmental location
Deceleration
require less
affects
such as
such as
such as
work by
i.e.
Egress heading and altitude
Level
Dive toss
Fragmentation
Iron bomb
Dive
allows for more
increases
Maneuverability
Adjustment time
Accuracy

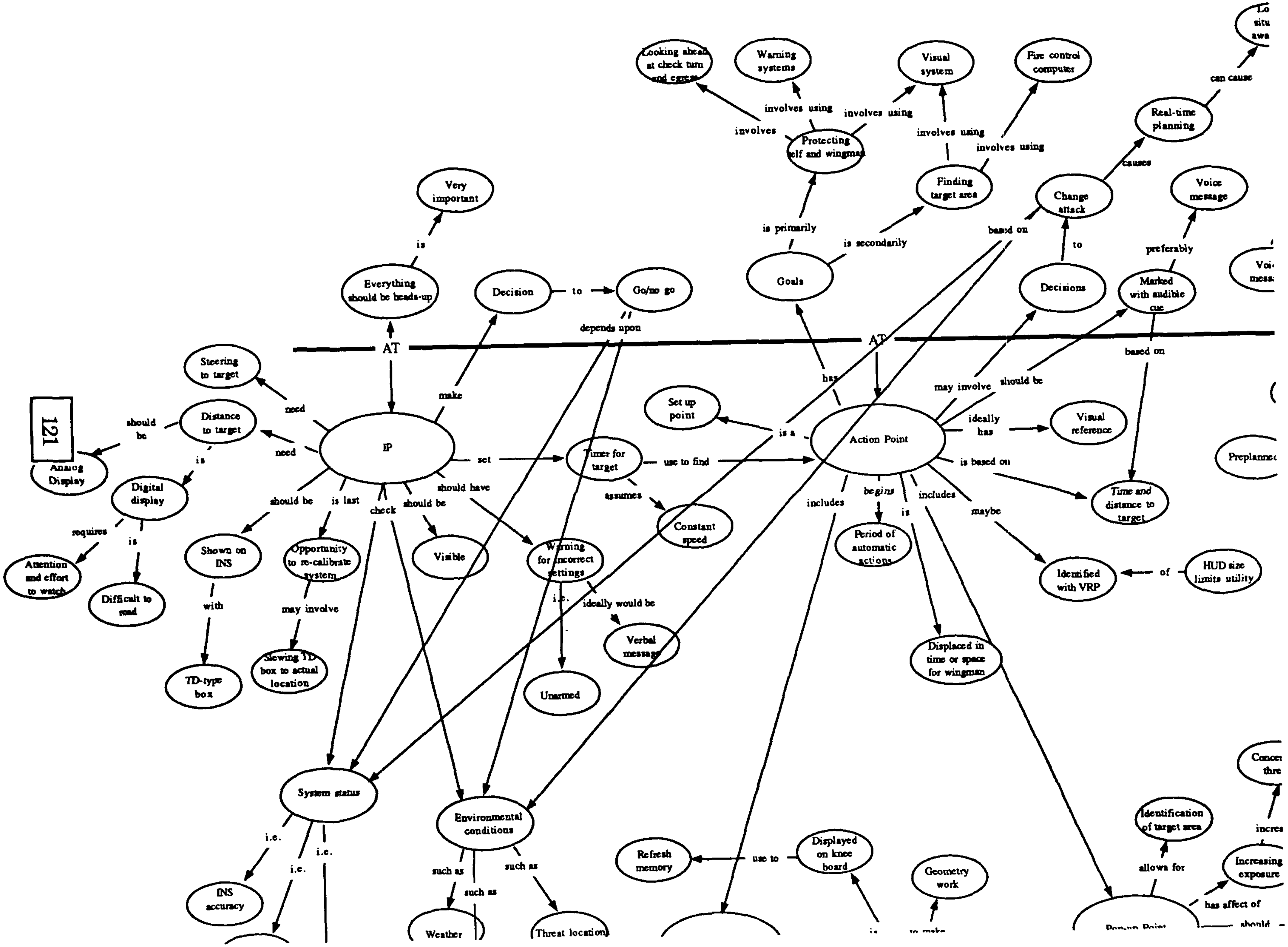


spiral
Weapon delivery modes
including
including
Constantly computed impact point (CCIP)
is
give display of
difficult to use for
Step switch
to
to
Most accurate delivery mode
Level delivery
Impact point
is
Projected on ground surface
from
Weather
may be used in
Constant computed release point (CCRP)
is a
Blind delivery mode
typically
equivalent to
not for
uses
involves
Holding thumb on pickle, and letting jet drop bomb on someting
Not used
Computer release of weapon
Radar to find target position
Visual scenario
when
and upon reaching
Pickle button has been pushed
then
maintain
pull
Prescribed course
A/C to climb altitude
Dive
is a
Radar computed delivery mode
High altitude release
to avoid
Fragmentation

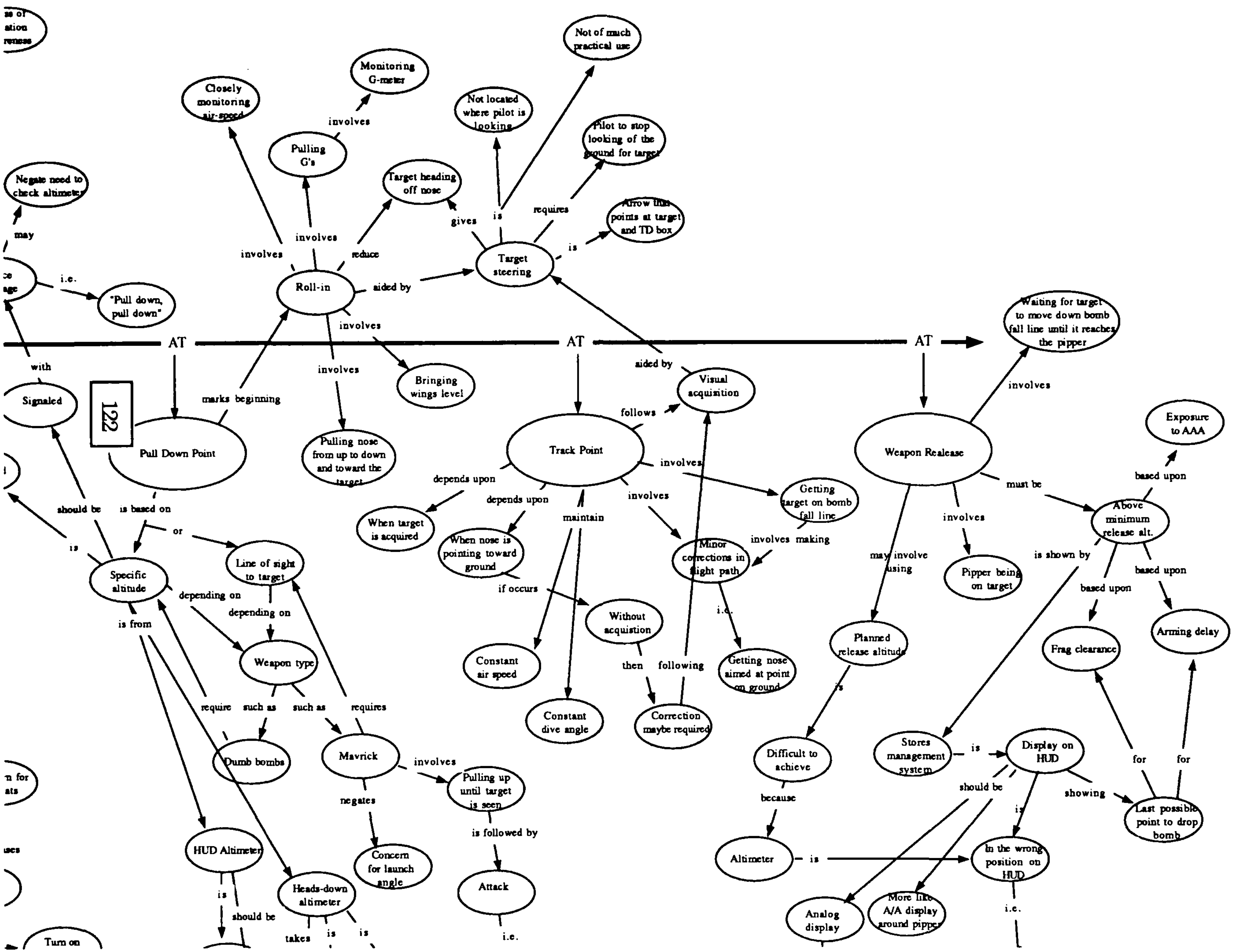

and actual location
Pull down point
F-4's system
involves
requires using
is
Unreliable
fosters
Pilot dependency
Knowing time, distance & heading
requires
Hacking clock
keeps
Heads down
requires
Constant air speed
Flying point-to-point
Dead reckoning

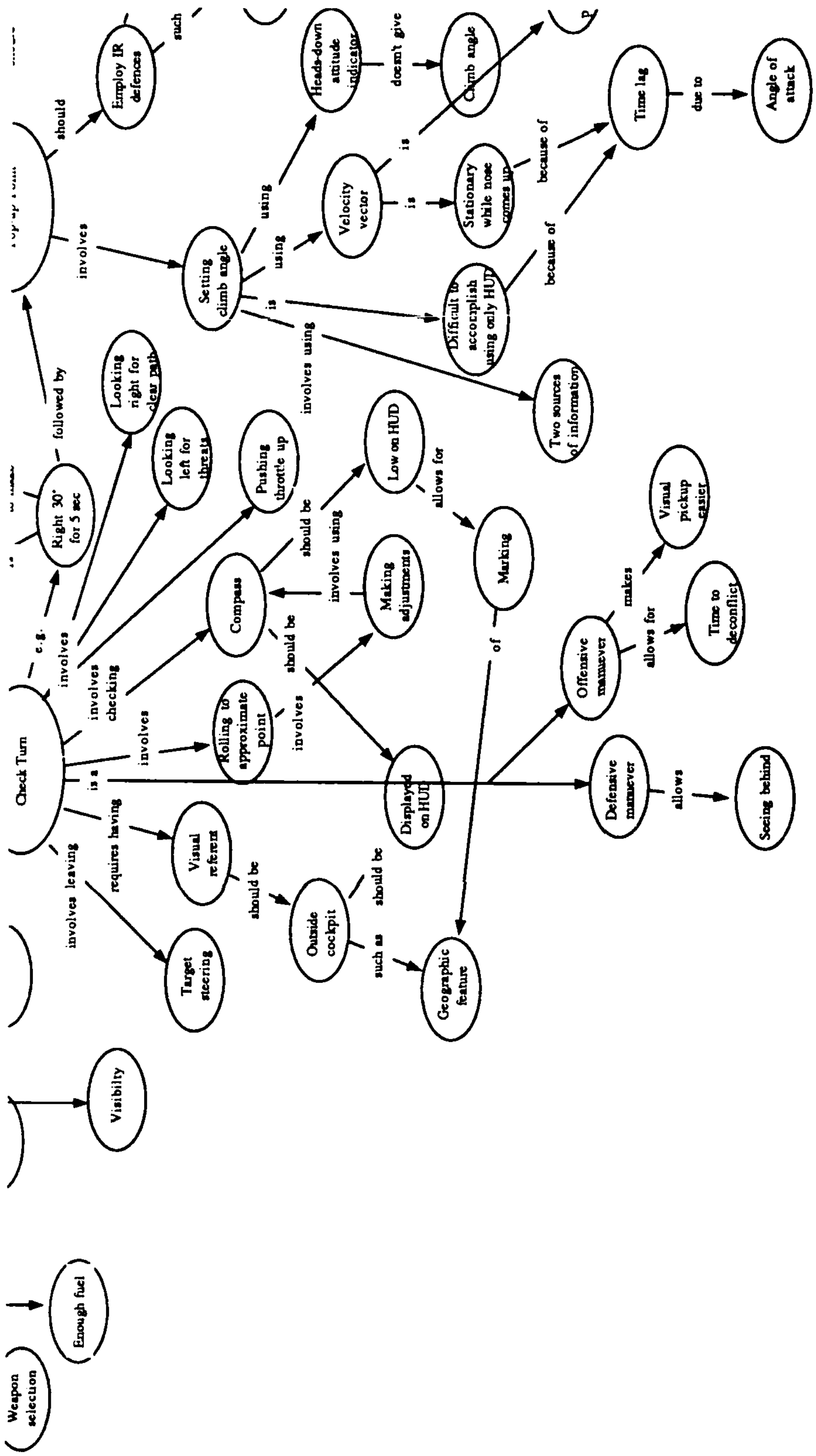

Stand-off delivery
is for
toss (DTOS)
delivery procedure
position
press
begin
Piper
Pickel button
Box
Pull-up
displays
may be used by
TD Box
can be moved with
X-Y axis button
Second ship in
on
to
Target
release
Bomb
determined by
Computer



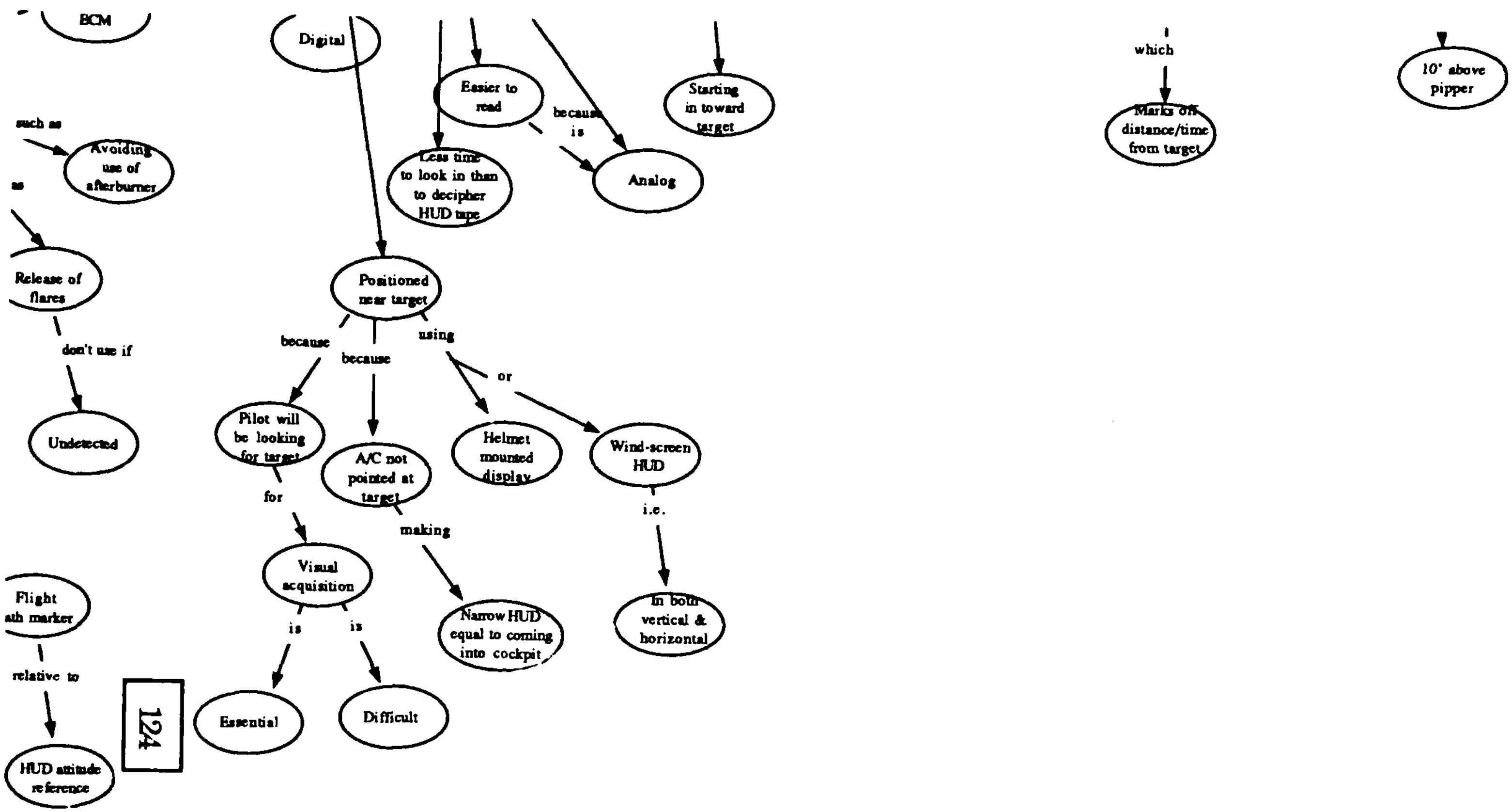


Looking ahead at check turn and egress
Warning systems
Visual system
Fire control computer
involves
involves using
involves using
involves using
involves using
Protecting self and wingman
Finding target area
Real-time planning
can cause
causes
Change attack
Voice message
Very important
is
is primarily
is secondarily
based on
to
preferably
Everything should be heads-up
Decision
to
Go/no go
Goals
Decisions
Marked with audible cue
depends upon
AT
AT
based on
Steering to target
need
make
has
may involve
should be
Distance to target
should be
need
IP
Set up point
is a
Action Point
ideally has
Visual reference
Preplanned
Analog Display
is
set
Timer for target
use to find
is based on
Digital display
should be
is last
check
should be
should have
assumes
includes
begins
is
includes
maybe
Time and distance to target
requires
is
Shown on INS
Opportunity to re-calibrate system
Visible
Warning for incorrect settings
Constant speed
Period of automatic actions
Identified with VRP
of
HUD size limits utility
Attention and effort to watch
Difficult to read
with
may involve
i.e.
ideally would be
Verbal message
Displaced in time or space for wingman
TD-type box
Slewing TD box to actual location
Unarmed
System status
Environmental conditions
i.e.
i.e.
i.e.
such as
such as
such as
INS accuracy
Weather
Threat location
Refresh memory
use to
Displayed on knee board
Geometry work
Identification of target area
allows for
Increasing exposure
has affect of
should


AT
AT
AT
Negate need to check altimeter
may
i.e.
"Pull down, pull down"
with
Signaled
should be
is
Closely monitoring air-speed
Pulling G's
involves
Monitoring G-meter
involves
involves
Roll-in
reduce
Target heading off nose
aided by
involves
Bringing wings level
involves
Pulling nose from up to down and toward the target
marks beginning
Pull Down Point
is based on
or
Target steering
gives
is
Not located where pilot is looking
Not of much practical use
requires
Pilot to stop looking of the ground for target
is
Arrow that points at target and TD box
aided by
Visual acquisition
follows
Track Point
depends upon
When target is acquired
depends upon
When nose is pointing toward ground
if occurs
Without acquistion
then
Correction maybe required
following
maintain
Constant air speed
Constant dive angle
involves
Getting target on bomb fall line
involves
Minor corrections in flight path
involves making
i.e.
Getting nose aimed at point on ground
Specific altitude
is from
depending on
Line of sight to target
depending on
Weapon type
such as
Dumb bombs
such as
Mavrick
require
requires
involves
Pulling up until target is seen
is followed by
Attack
i.e.
negates
Concern for launch angle
HUD Altimeter
is
should be
Heads-down altimeter
takes
is
is
Turn on
Weapon Realease
involves
Waiting for target to move down bomb fall line until it reaches the pipper
involves
Pipper being on target
may involve using
Planned release altitude
is
Difficult to achieve
because
Altimeter
is
must be
Above minimum release alt.
based upon
Exposure to AAA
based upon
Frag clearance
based upon
Arming delay
is shown by
Stores management system
is
Display on HUD
should be
Analog display
More like A/A display around pipper
is
In the wrong position on HUD
i.e.
showing
Last possible point to drop bomb
for
for



Check Turn
e.g.
Right 30° for 5 sec
followed by
involves
Looking right for clear path
Looking left for threats
Pushing throttle up
involves checking
Compass
should be
should be
Low on HUD
allows for
Marking
of
involves using
Making adjustments
involves
Rolling to approximate point
involves
Displayed on HUD
is a
Offensive maneuver
makes
Visual pickup easier
allows for
Time to deconflict
Defensive maneuver
allows
Seeing behind
requires having
Visual referent
should be
Outside cockpit
should be
such as
Geographic feature
involves leaving
Target steering
involves
Setting climb angle
using
Heads-down attitude indicator
doesn't give
Climb angle
using
Velocity vector
is
is
Stationary while nose comes up
because of
Time lag
due to
Angle of attack
is
Difficult to accomplish using only HUD
because of
involves using
Two sources of information
should
Employ IR defences
such
Visibility
Enough fuel
Weapon selection


BCM
Digital
Easier to read
because is
Starting in toward target
Less time to look in than to decipher HUD tape
Analog
which
Marks off distance/time from target
10° above pipper
such as
Avoiding use of afterburner
as
Release of flares
don't use if
Undetected
Positioned near target
because
because
using
or
Pilot will be looking for target
A/C not pointed at target
Helmet mounted display
Wind-screen HUD
i.e.
In both vertical & horizontal
for
making
Visual acquisition
Narrow HUD equal to coming into cockpit
is
is
Essential
Difficult
Flight ath marker
relative to
HUD attitude reference

APPENDIX B

$IDEF_0$ MODEL

USED AT:	AUTHOR: J. DUNCAN PROJECT: PILOT ASSOCIATE: AIR GROUND NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 7/10/90 REV:	x	WORKING	READER DATE	CONTEXT:
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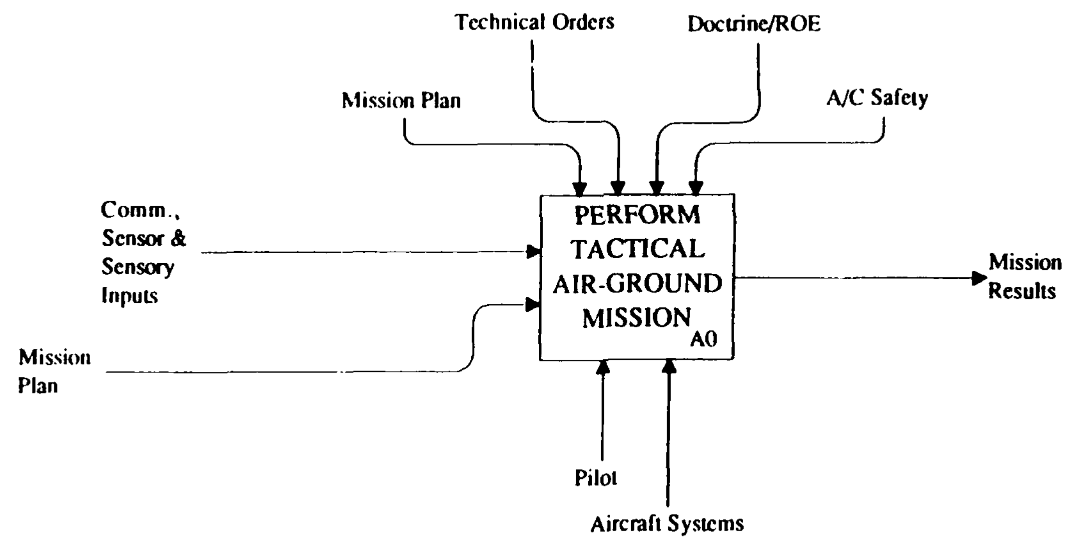
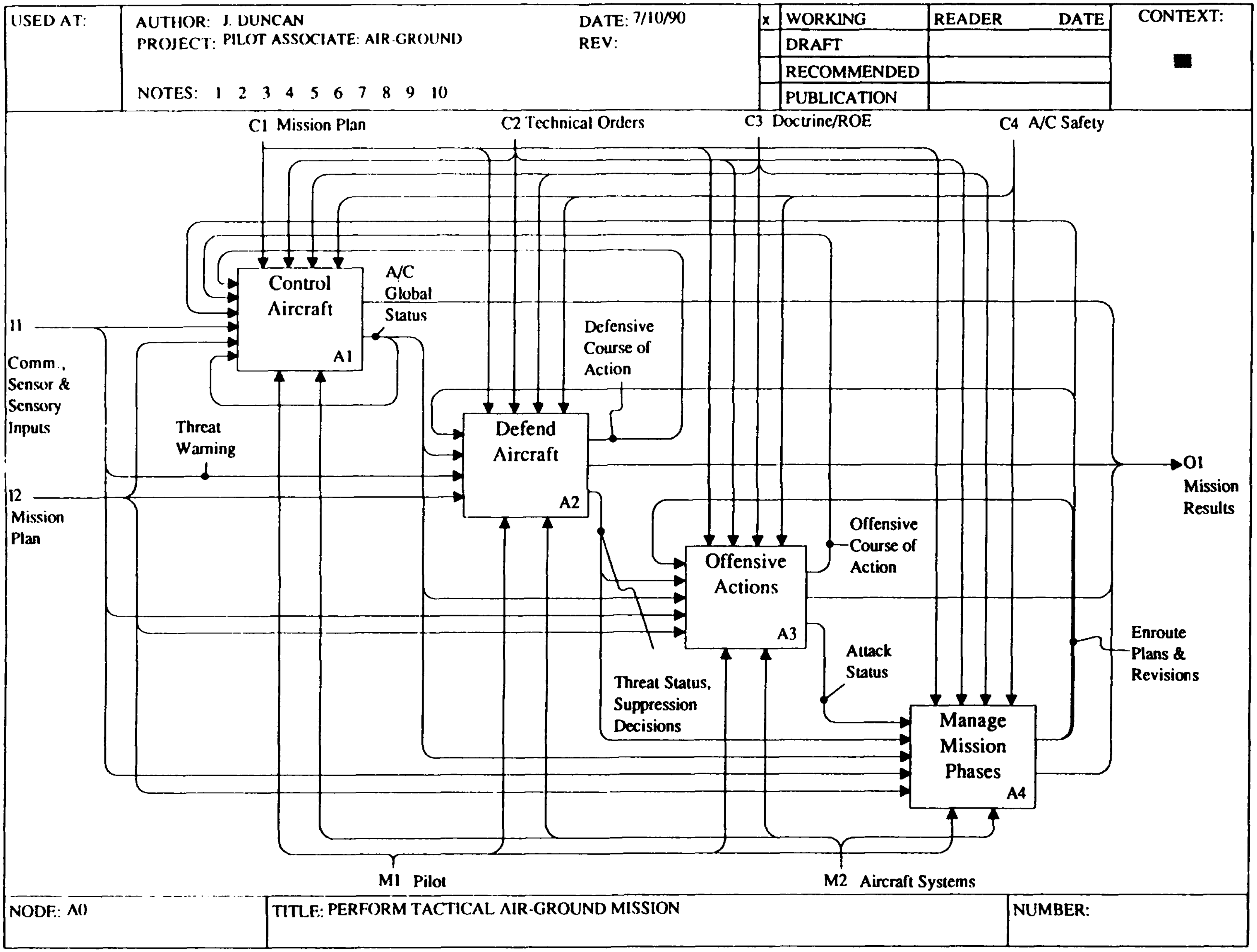
				RECOMMENDED		
				PUBLICATION		



Context: Perform Tactical Air -Ground Mission, Emphasis on Ingress-Target Attack-Egress Mission Segments
Viewpoint: Pilot Task Requirements
Purpose: Develop Descriptive Model of Tactical Air-Ground Mission to be used for
1) KA guidance in Pilot Information/Decision Analysis
2) Basis for Computer Simulation of Mission Execution and Pilot Information Requirements

NODE: A-0	TITLE: PERFORM TACTICAL AIR-GROUND MISSION	NUMBER: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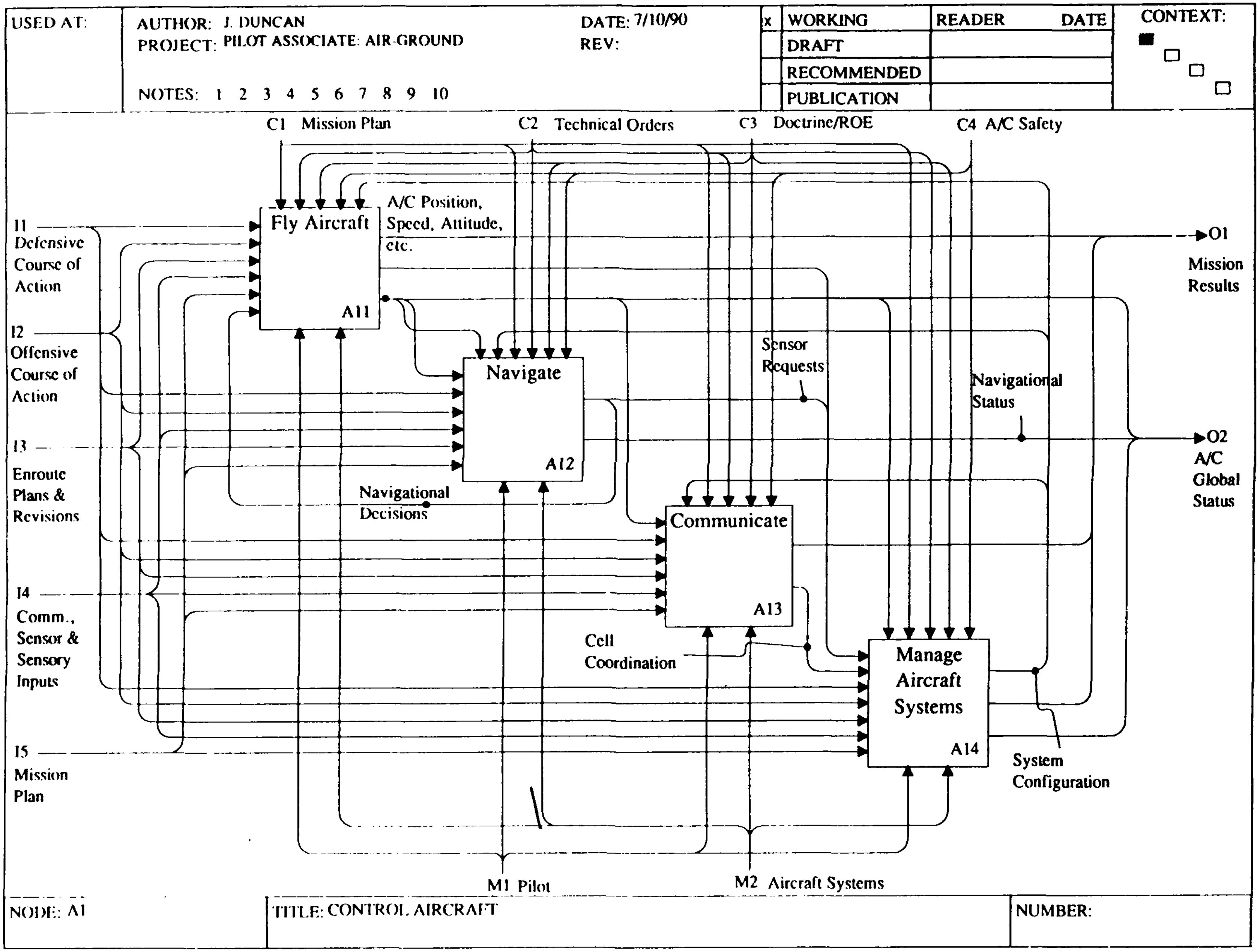
PROJECT: PILOT ASSOCIATE: AIR-GROUND
DATE: 7/10/90
REV:
NOTES: 1 2 3 4 5 6 7 8 9 10
x WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER DATE
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 A/C Safety
I1
Comm., Sensor & Sensory Inputs
I2 Mission Plan
Control Aircraft
A1
A/C Global Status
Threat Warning
Defend Aircraft
A2
Defensive Course of Action
Offensive Actions
A3
Offensive Course of Action
Threat Status, Suppression Decisions
Attack Status
Manage Mission Phases
A4
Enroute Plans & Revisions
O1 Mission Results
M1 Pilot
M2 Aircraft Systems
NODE: A0
TITLE: PERFORM TACTICAL AIR-GROUND MISSION
NUMBER:



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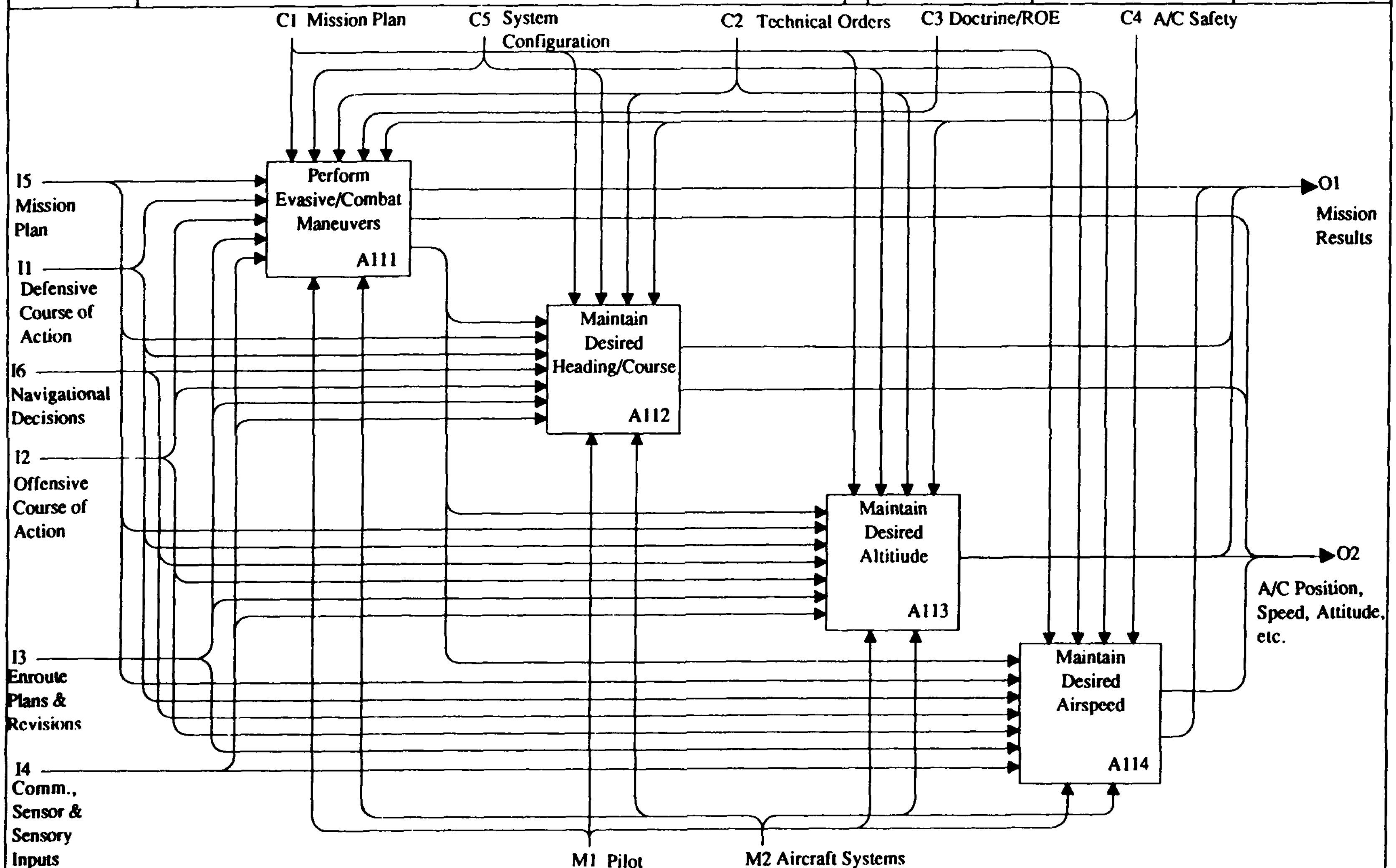
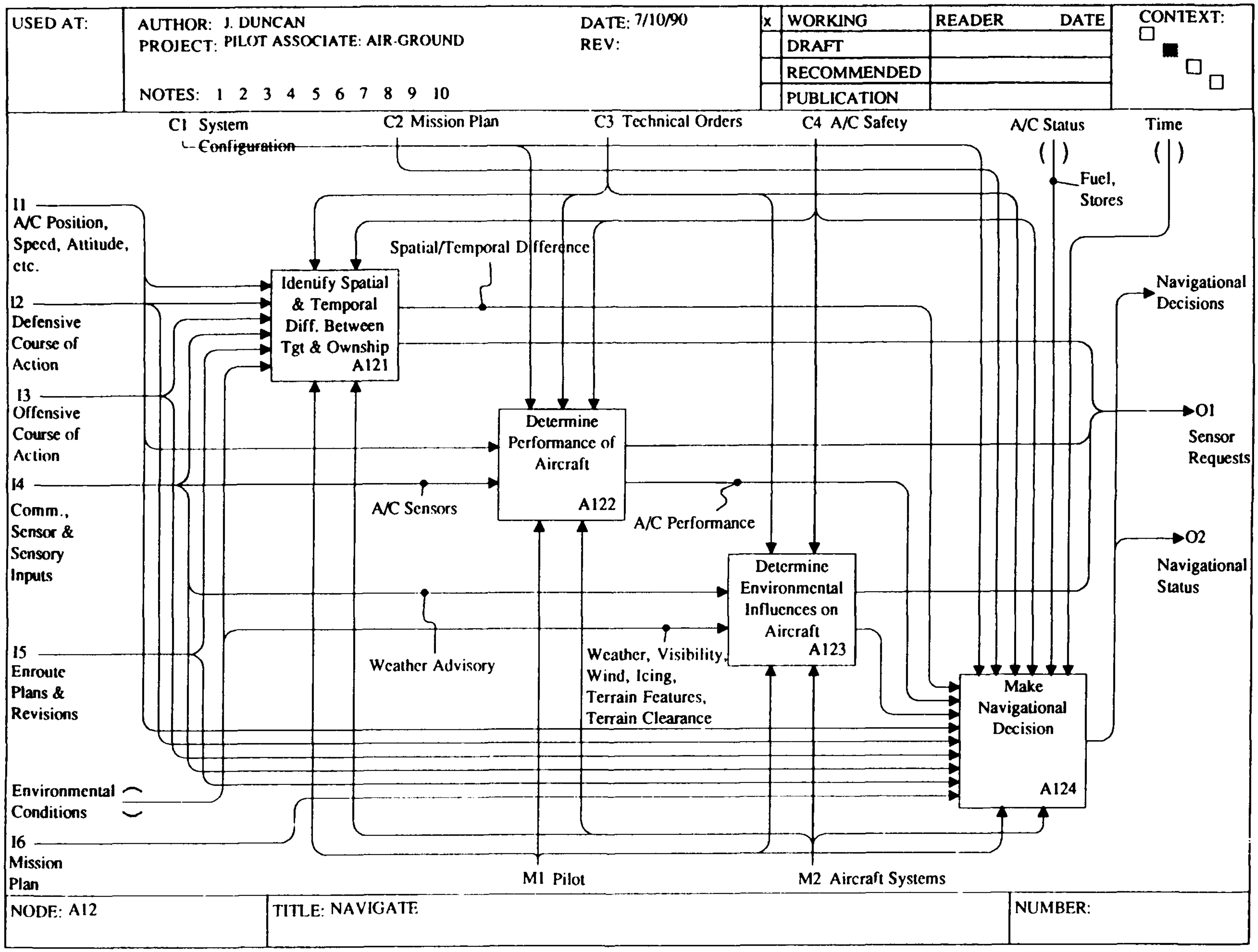
PROJECT: PILOT ASSOCIATE: AIR-GROUND
DATE: 7/10/90
REV:
NOTES: 1 2 3 4 5 6 7 8 9 10
x WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 A/C Safety
I1 Defensive Course of Action
I2 Offensive Course of Action
I3 Enroute Plans & Revisions
I4 Comm., Sensor & Sensory Inputs
I5 Mission Plan
Fly Aircraft
A11
A/C Position, Speed, Attitude, etc.
Navigate
A12
Navigational Decisions
Sensor Requests
Communicate
A13
Cell Coordination
Navigational Status
Manage Aircraft Systems
A14
System Configuration
O1 Mission Results
O2 A/C Global Status
M1 Pilot
M2 Aircraft Systems
NODE: A1
TITLE: CONTROL AIRCRAFT
NUMBER:

USED AT:	AUTHOR: J. DUNCAN PROJECT: PILOT ASSOCIATE: AIR-GROUND NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 7/10/90 REV:	x WORKING DRAFT RECOMMENDED PUBLICATION	READER	DATE	CONTEXT:



NODE: A11	TITLE: FLY AIRCRAFT	NUMBER: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PROJECT: PILOT ASSOCIATE: AIR-GROUND
DATE: 7/10/90
REV:
NOTES: 1 2 3 4 5 6 7 8 9 10
x WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
C1 System Configuration
C2 Mission Plan
C3 Technical Orders
C4 A/C Safety
A/C Status
Time
Fuel, Stores
I1 A/C Position, Speed, Attitude, etc.
I2 Defensive Course of Action
I3 Offensive Course of Action
I4 Comm., Sensor & Sensory Inputs
I5 Enroute Plans & Revisions
Environmental Conditions
I6 Mission Plan
Identify Spatial & Temporal Diff. Between Tgt & Ownship A121
Spatial/Temporal Difference
Determine Performance of Aircraft A122
A/C Sensors
A/C Performance
Determine Environmental Influences on Aircraft A123
Weather Advisory
Weather, Visibility, Wind, Icing, Terrain Features, Terrain Clearance
Make Navigational Decision A124
Navigational Decisions
O1 Sensor Requests
O2 Navigational Status
M1 Pilot
M2 Aircraft Systems
NODE: A12
TITLE: NAVIGATE
NUMBER:

USED AT:	AUTHOR: J. DUNCAN PROJECT: PILOT ASSOCIATE: AIR-GROUND NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 7/10/90 REV:	x	WORKING	READER	DATE	CONTEXT:
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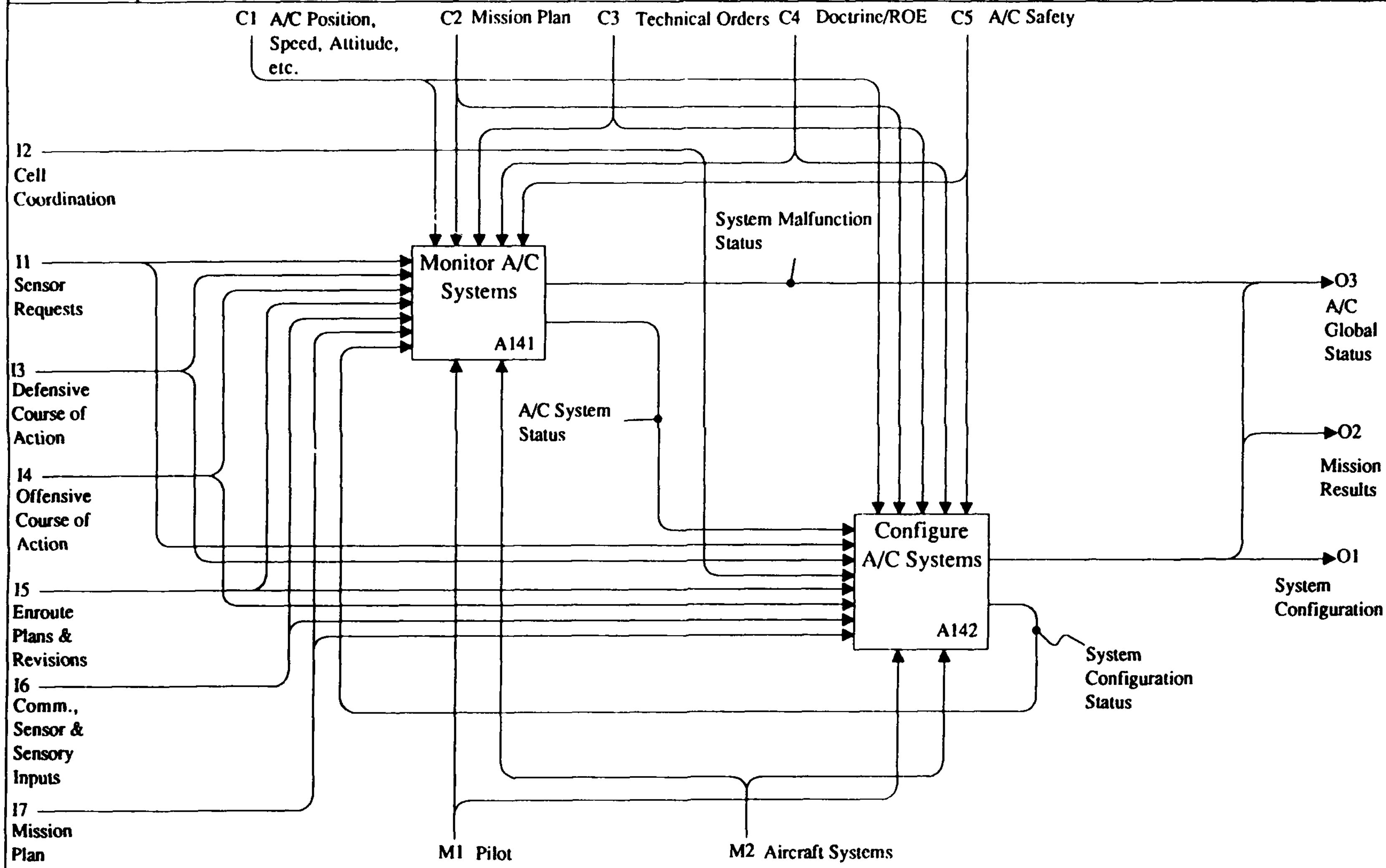

NODE: A14	TITLE: MANAGE AIRCRAFT SYSTEMS	NUMBER:

USED AT:	AUTHOR: J. DUNCAN PROJECT: PILOT ASSOCIATE: AIR-GROUND NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 7/10/90 REV:	x	WORKING	READER	DATE	CONTEXT:
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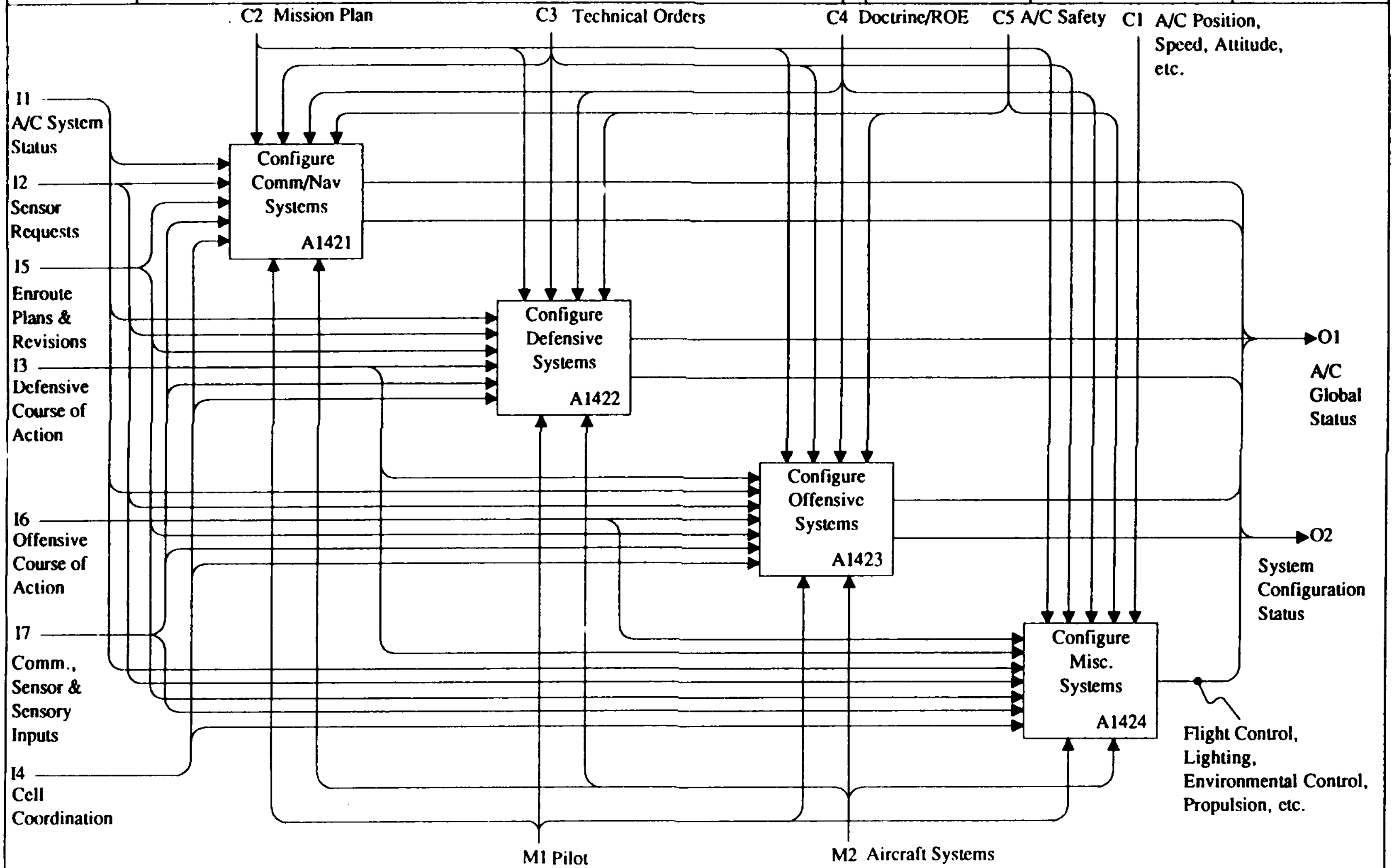
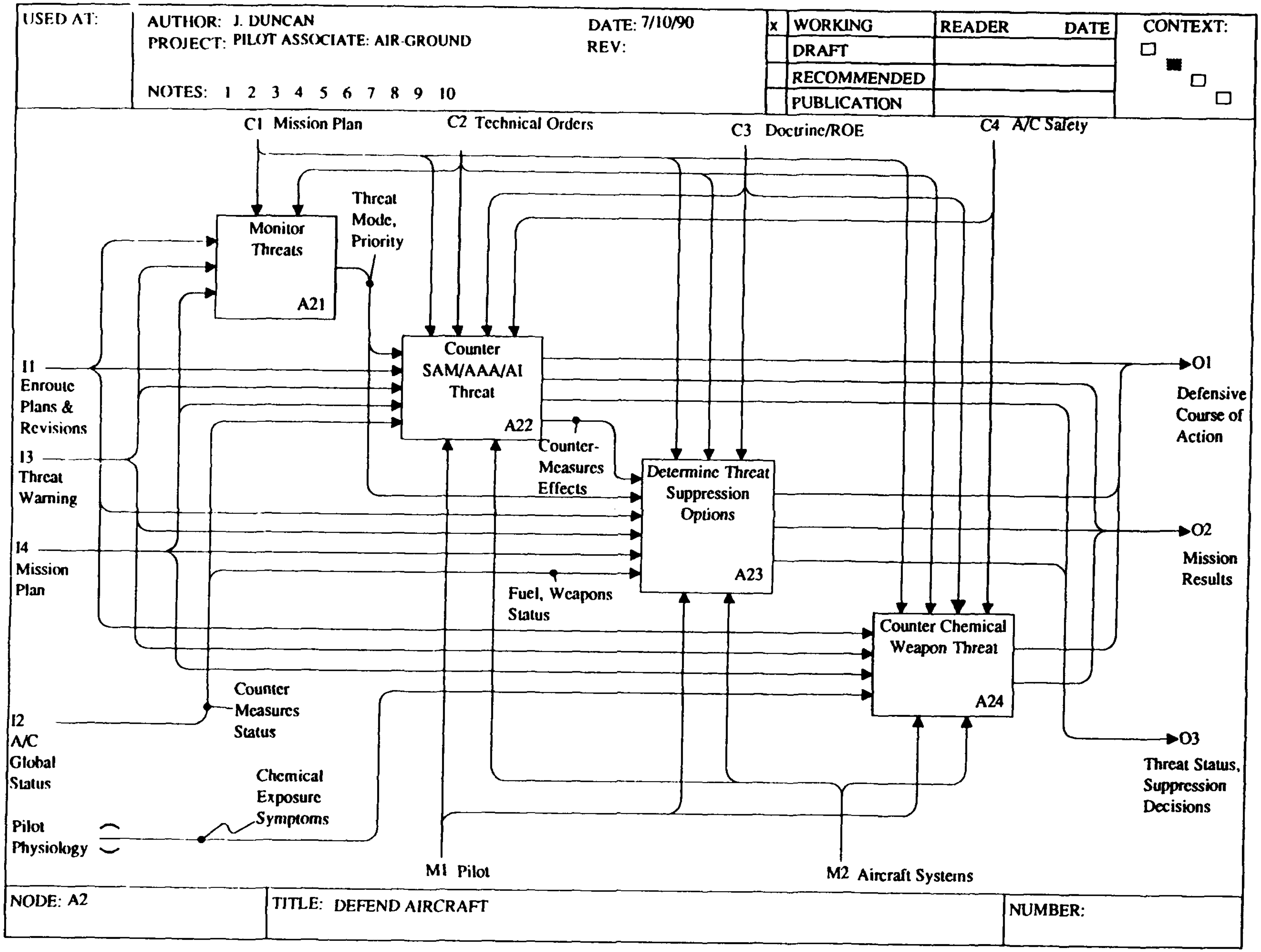


NODE: A142	TITLE: CONFIGURE A/C SYSTEMS	NUMBER: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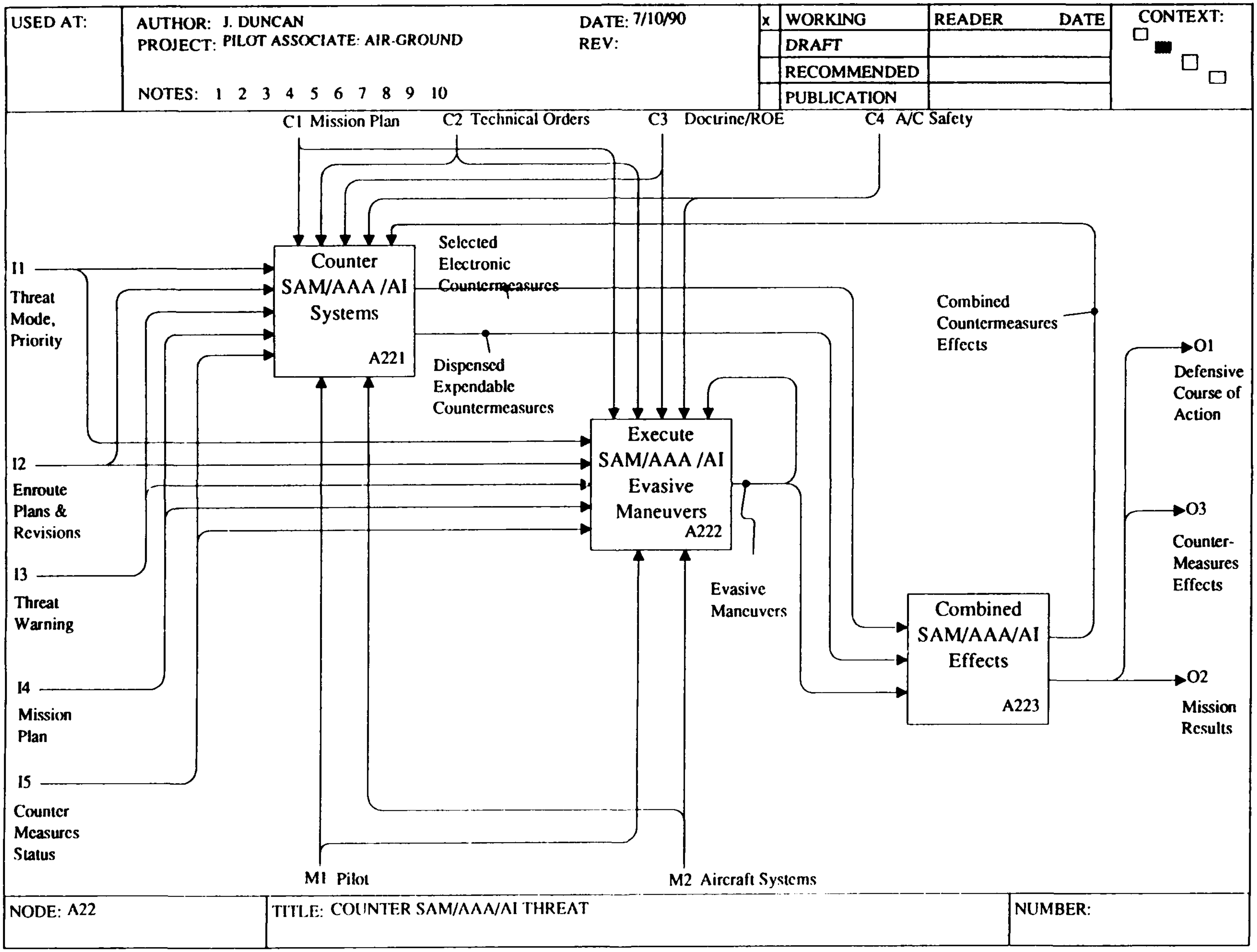
NOTES: 1 2 3 4 5 6 7 8 9 10
DATE: 7/10/90
REV:
x WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 A/C Safety
Monitor Threats
A21
Threat Mode, Priority
Counter SAM/AAA/AI Threat
A22
Counter-Measures Effects
Determine Threat Suppression Options
A23
Fuel, Weapons Status
Counter Chemical Weapon Threat
A24
I1 Enroute Plans & Revisions
I3 Threat Warning
I4 Mission Plan
I2 A/C Global Status
Counter Measures Status
Chemical Exposure Symptoms
Pilot Physiology
O1 Defensive Course of Action
O2 Mission Results
O3 Threat Status, Suppression Decisions
M1 Pilot
M2 Aircraft Systems
NODE: A2
TITLE: DEFEND AIRCRAFT
NUMBER: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PROJECT: PILOT ASSOCIATE: AIR-GROUND
NOTES: 1 2 3 4 5 6 7 8 9 10
DATE: 7/10/90
REV:
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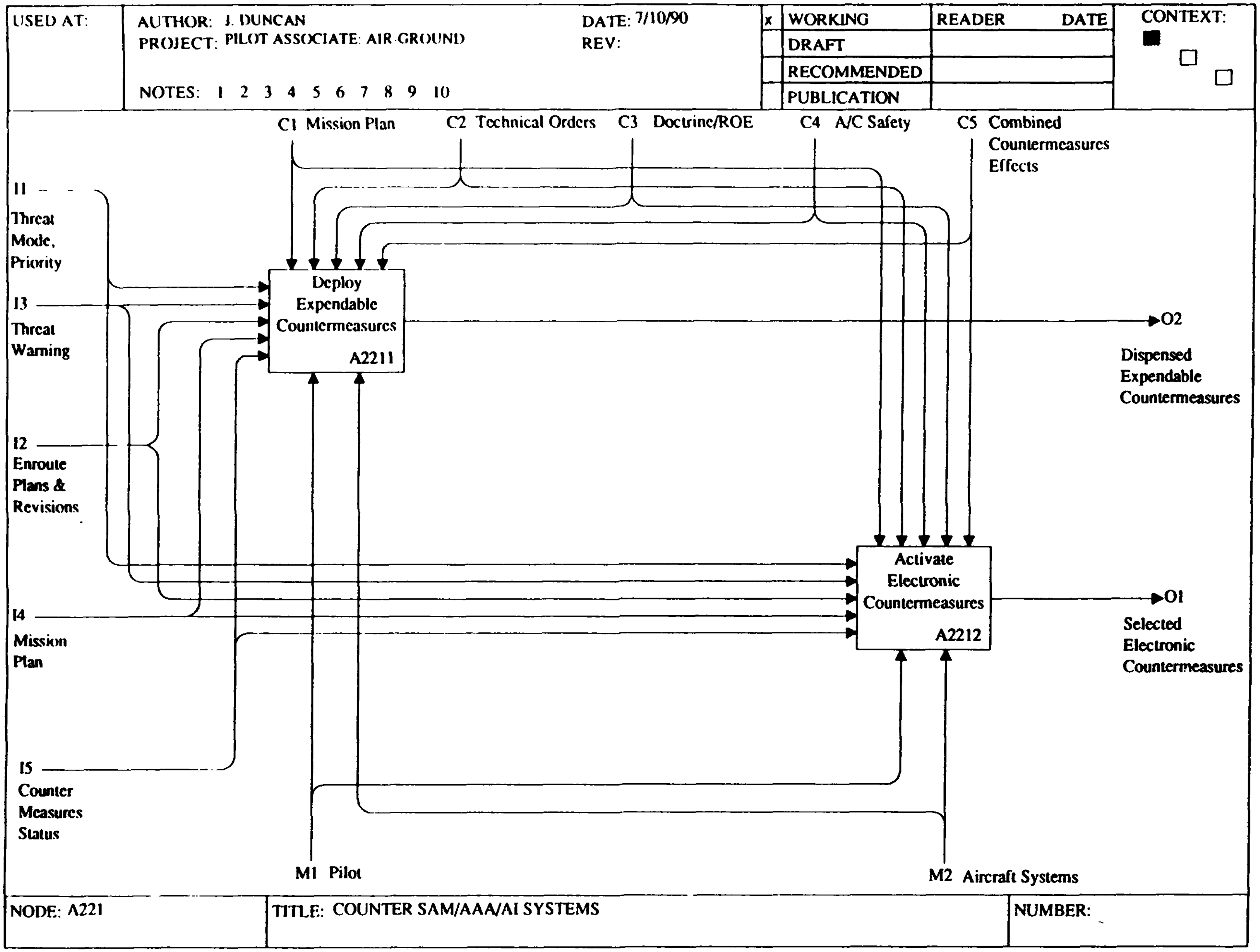
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 A/C Safety
I1 Threat Mode, Priority
I2 Enroute Plans & Revisions
I3 Threat Warning
I4 Mission Plan
I5 Counter Measures Status
Counter SAM/AAA /AI Systems
A221
Selected Electronic Countermeasures
Dispensed Expendable Countermeasures
Execute SAM/AAA /AI Evasive Maneuvers
A222
Evasive Maneuvers
Combined Countermeasures Effects
Combined SAM/AAA/AI Effects
A223
O1 Defensive Course of Action
O3 Counter-Measures Effects
O2 Mission Results
M1 Pilot
M2 Aircraft Systems
NODE: A22
TITLE: COUNTER SAM/AAA/AI THREAT
NUMBER: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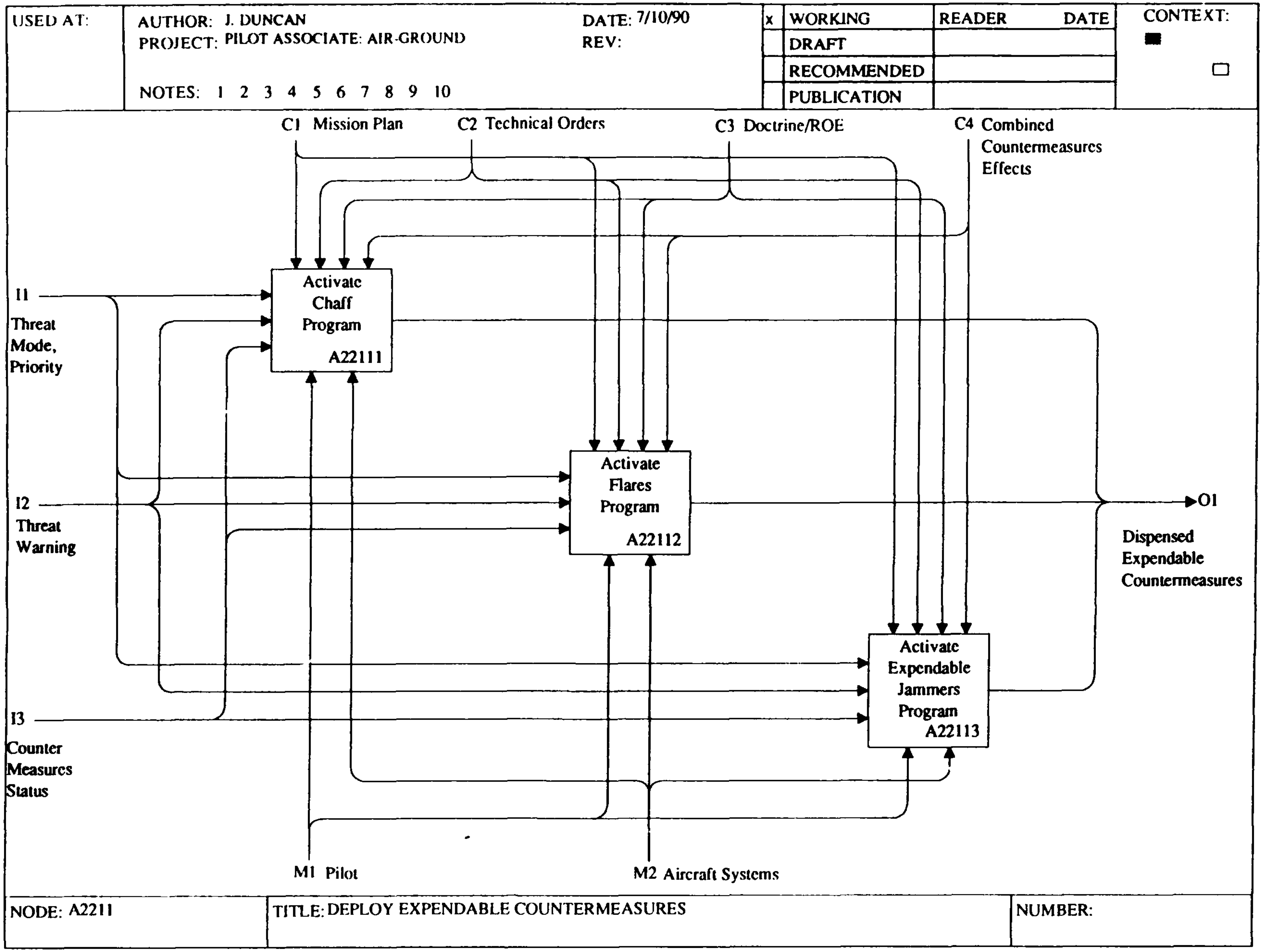
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 A/C Safety
C5 Combined Countermeasures Effects
I1 Threat Mode, Priority
I3 Threat Warning
I2 Enroute Plans & Revisions
I4 Mission Plan
I5 Counter Measures Status
Deploy Expendable Countermeasures
A2211
O2
Dispensed Expendable Countermeasures
Activate Electronic Countermeasures
A2212
O1
Selected Electronic Countermeasures
M1 Pilot
M2 Aircraft Systems
NODE: A221
TITLE: COUNTER SAM/AAA/AI SYSTEMS
NUMBER: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DATE: 7/10/90
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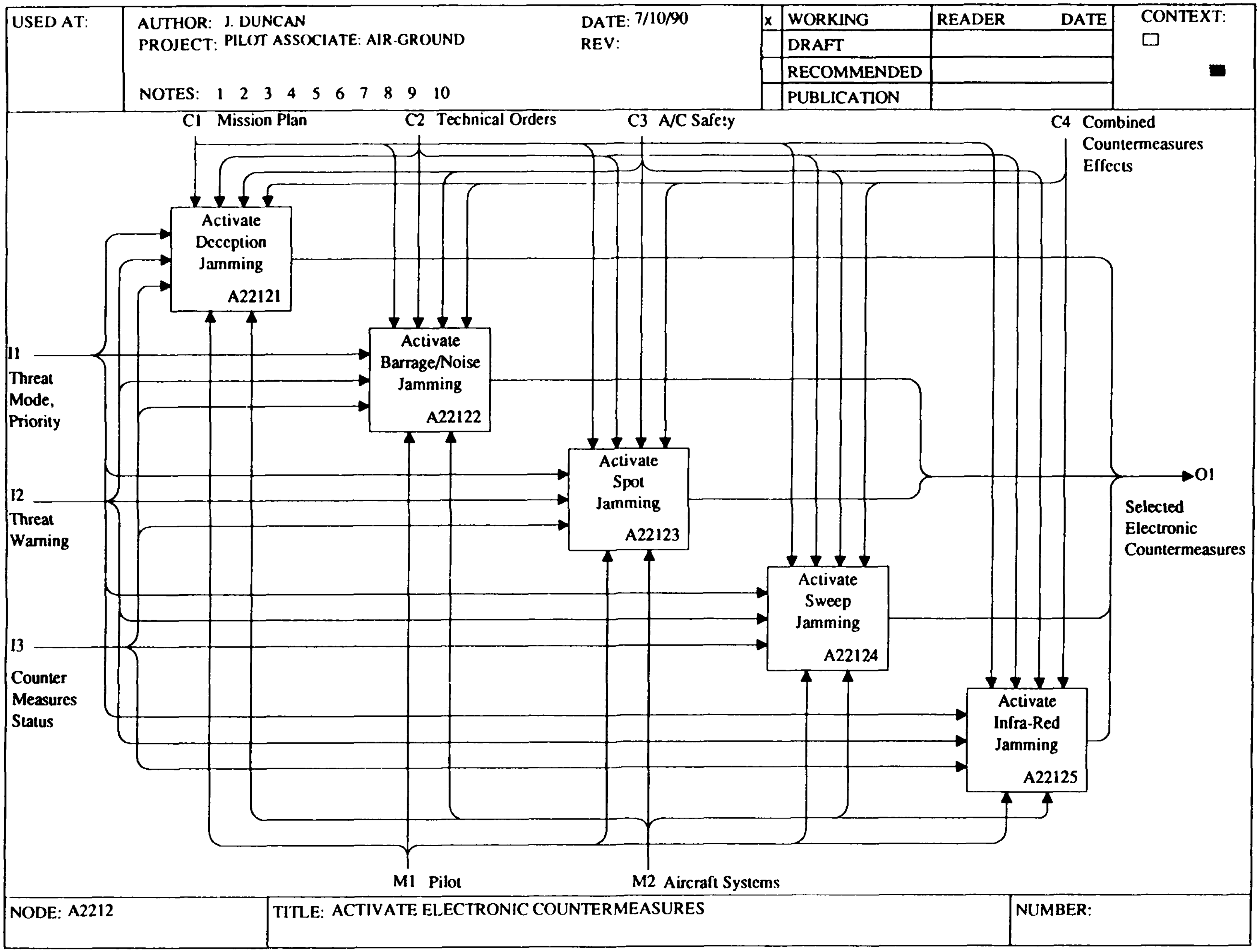
RECOMMENDED
PUBLICATION
READER DATE
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 Combined Countermeasures Effects
I1 Threat Mode, Priority
I2 Threat Warning
I3 Counter Measures Status
Activate Chaff Program A22111
Activate Flares Program A22112
Activate Expendable Jammers Program A22113
O1 Dispensed Expendable Countermeasures
M1 Pilot
M2 Aircraft Systems
NODE: A2211
TITLE: DEPLOY EXPENDABLE COUNTERMEASURES
NUMBER: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DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 A/C Safety
C4 Combined Countermeasures Effects
I1 Threat Mode, Priority
I2 Threat Warning
I3 Counter Measures Status
Activate Deception Jamming
A22121
Activate Barrage/Noise Jamming
A22122
Activate Spot Jamming
A22123
Activate Sweep Jamming
A22124
Activate Infra-Red Jamming
A22125
O1
Selected Electronic Countermeasures
M1 Pilot
M2 Aircraft Systems
NODE: A2212
TITLE: ACTIVATE ELECTRONIC COUNTERMEASURES
NUMBER:

USED AT:	AUTHOR: J. DUNCAN PROJECT: PILOT ASSOCIATE: AIR-GROUND NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 7/10/90 REV:	x	WORKING	READER	DATE	CONTEXT:
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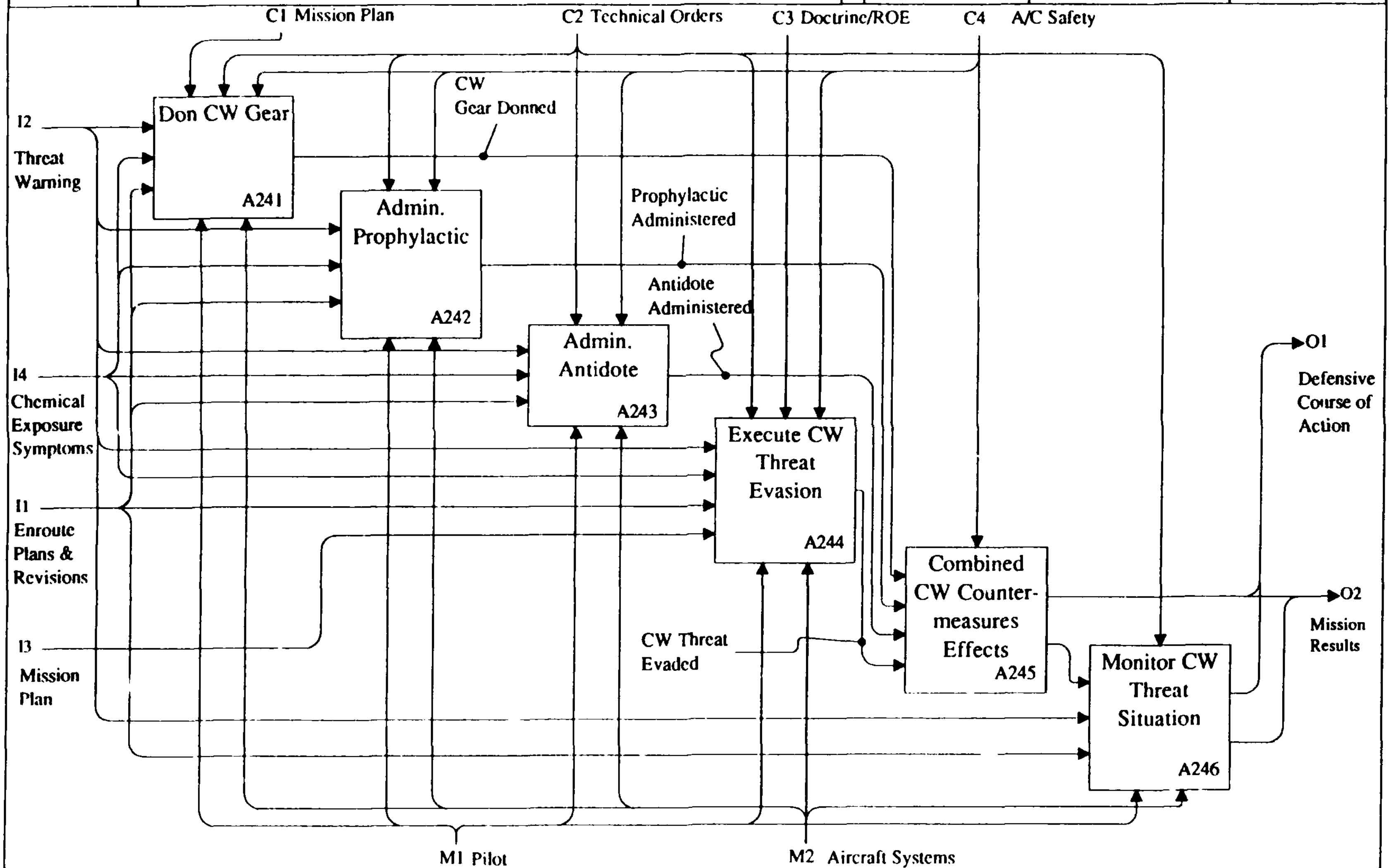
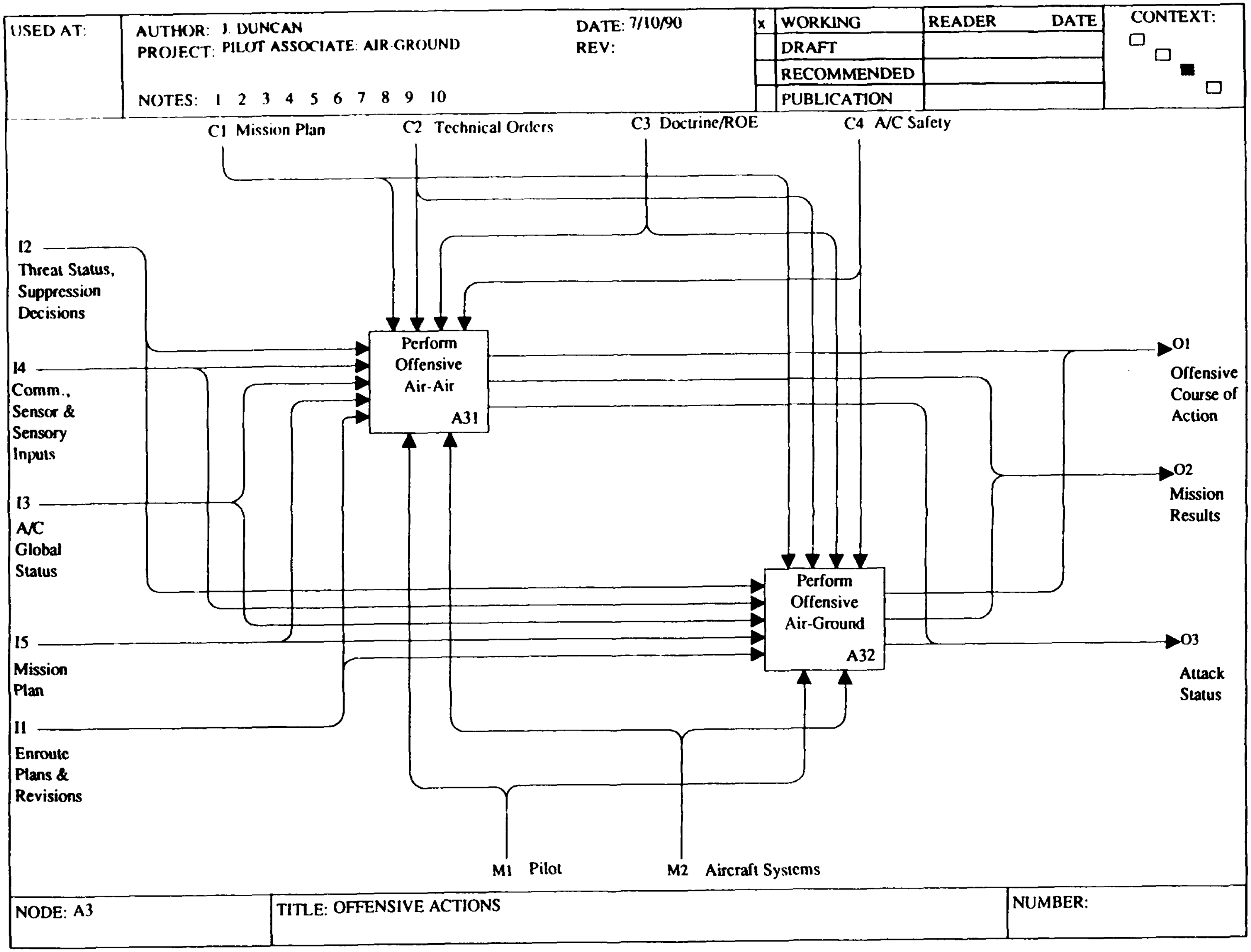


NODE: A24	TITLE: COUNTER CHEMICAL WEAPON THREAT	NUMBER: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PROJECT: PILOT ASSOCIATE: AIR-GROUND
NOTES: 1 2 3 4 5 6 7 8 9 10
DATE: 7/10/90
REV:
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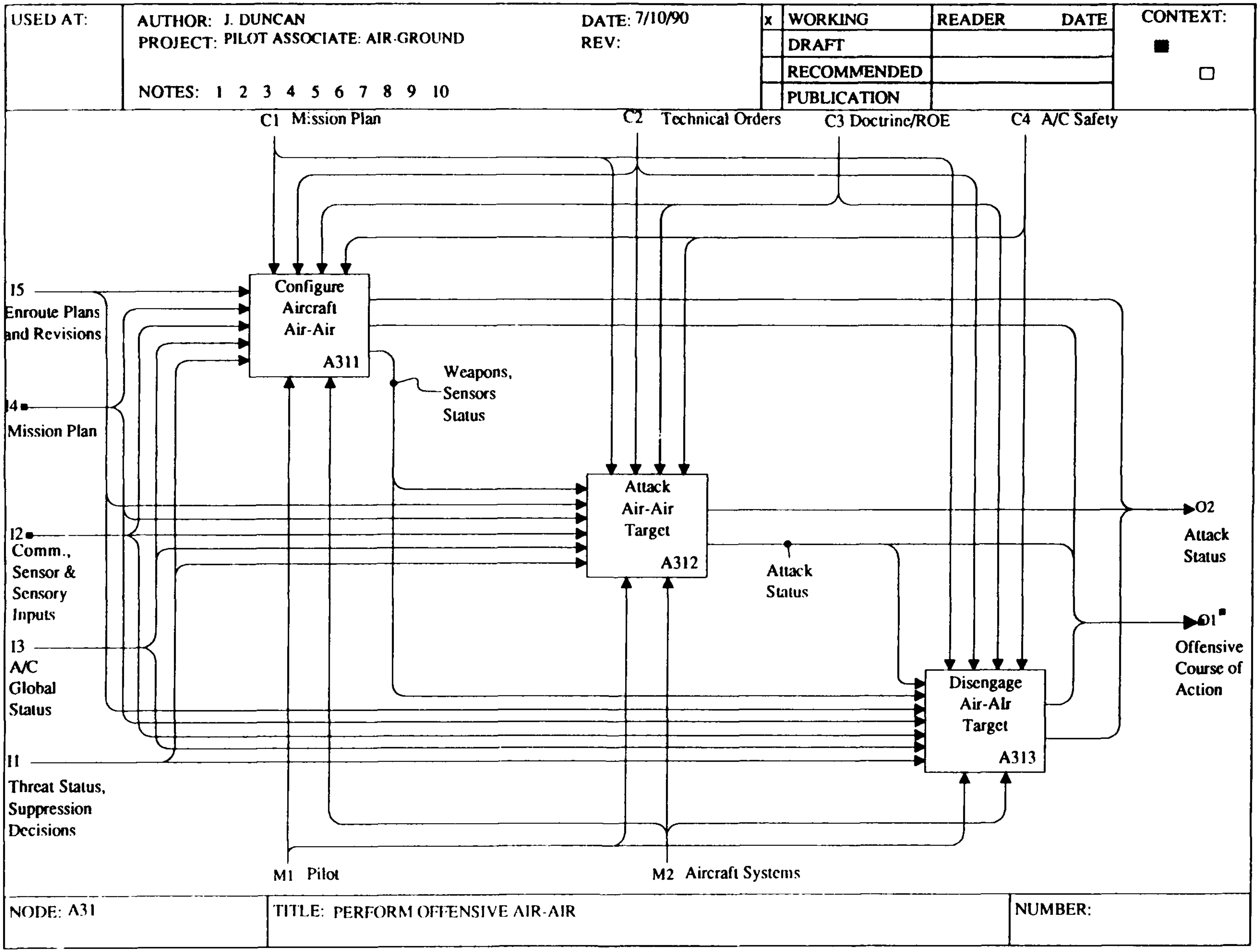
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 A/C Safety
I2 Threat Status, Suppression Decisions
I4 Comm., Sensor & Sensory Inputs
I3 A/C Global Status
I5 Mission Plan
I1 Enroute Plans & Revisions
Perform Offensive Air-Air
A31
Perform Offensive Air-Ground
A32
O1 Offensive Course of Action
O2 Mission Results
O3 Attack Status
M1 Pilot
M2 Aircraft Systems
NODE: A3
TITLE: OFFENSIVE ACTIONS
NUMBER: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NOTES: 1 2 3 4 5 6 7 8 9 10
DATE: 7/10/90
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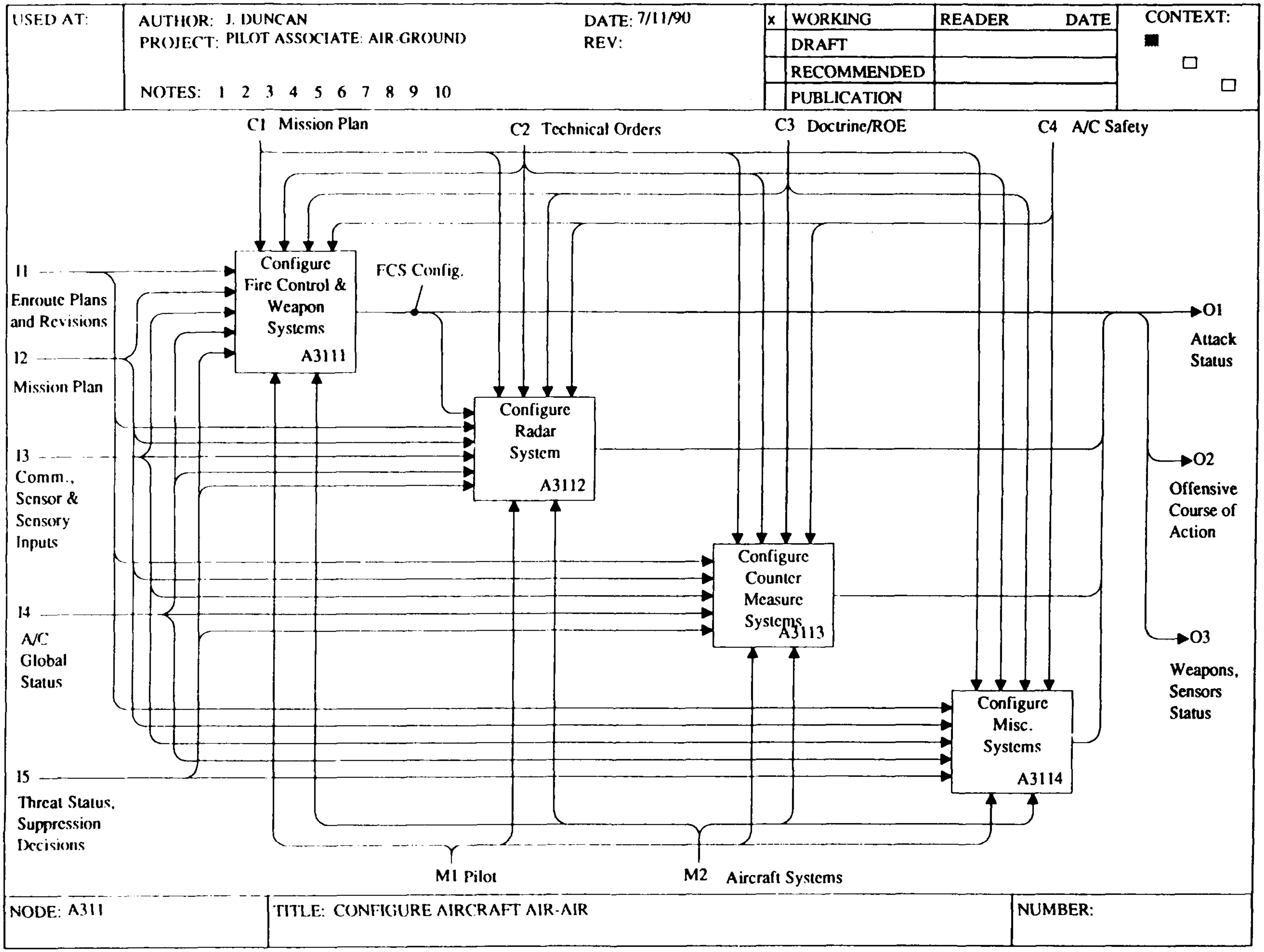
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 A/C Safety
I5 Enroute Plans and Revisions
I4 Mission Plan
I2 Comm., Sensor & Sensory Inputs
I3 A/C Global Status
I1 Threat Status, Suppression Decisions
Configure Aircraft Air-Air
A311
Weapons, Sensors Status
Attack Air-Air Target
A312
Attack Status
Disengage Air-Air Target
A313
O2 Attack Status
O1 Offensive Course of Action
M1 Pilot
M2 Aircraft Systems
NODE: A31
TITLE: PERFORM OFFENSIVE AIR-AIR
NUMBER: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DATE: 7/11/90
REV:
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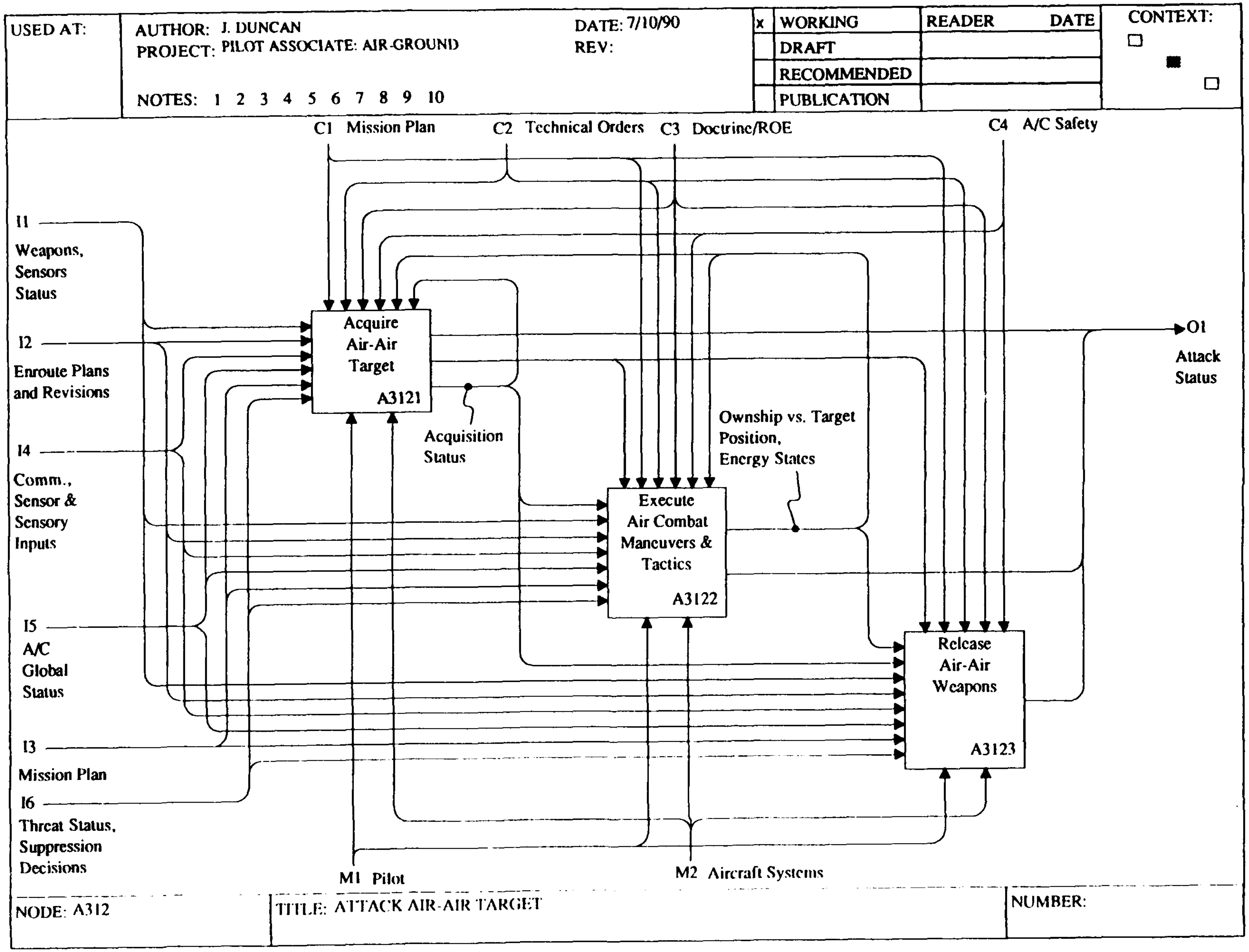
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 A/C Safety
I1 Enroute Plans and Revisions
I2 Mission Plan
I3 Comm., Sensor & Sensory Inputs
I4 A/C Global Status
I5 Threat Status, Suppression Decisions
Configure Fire Control & Weapon Systems A3111
FCS Config.
Configure Radar System A3112
Configure Counter Measure Systems A3113
Configure Misc. Systems A3114
O1 Attack Status
O2 Offensive Course of Action
O3 Weapons, Sensors Status
M1 Pilot
M2 Aircraft Systems
NODE: A311
TITLE: CONFIGURE AIRCRAFT AIR-AIR
NUMBER: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PROJECT: PILOT ASSOCIATE: AIR-GROUND
DATE: 7/10/90
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READER
DATE
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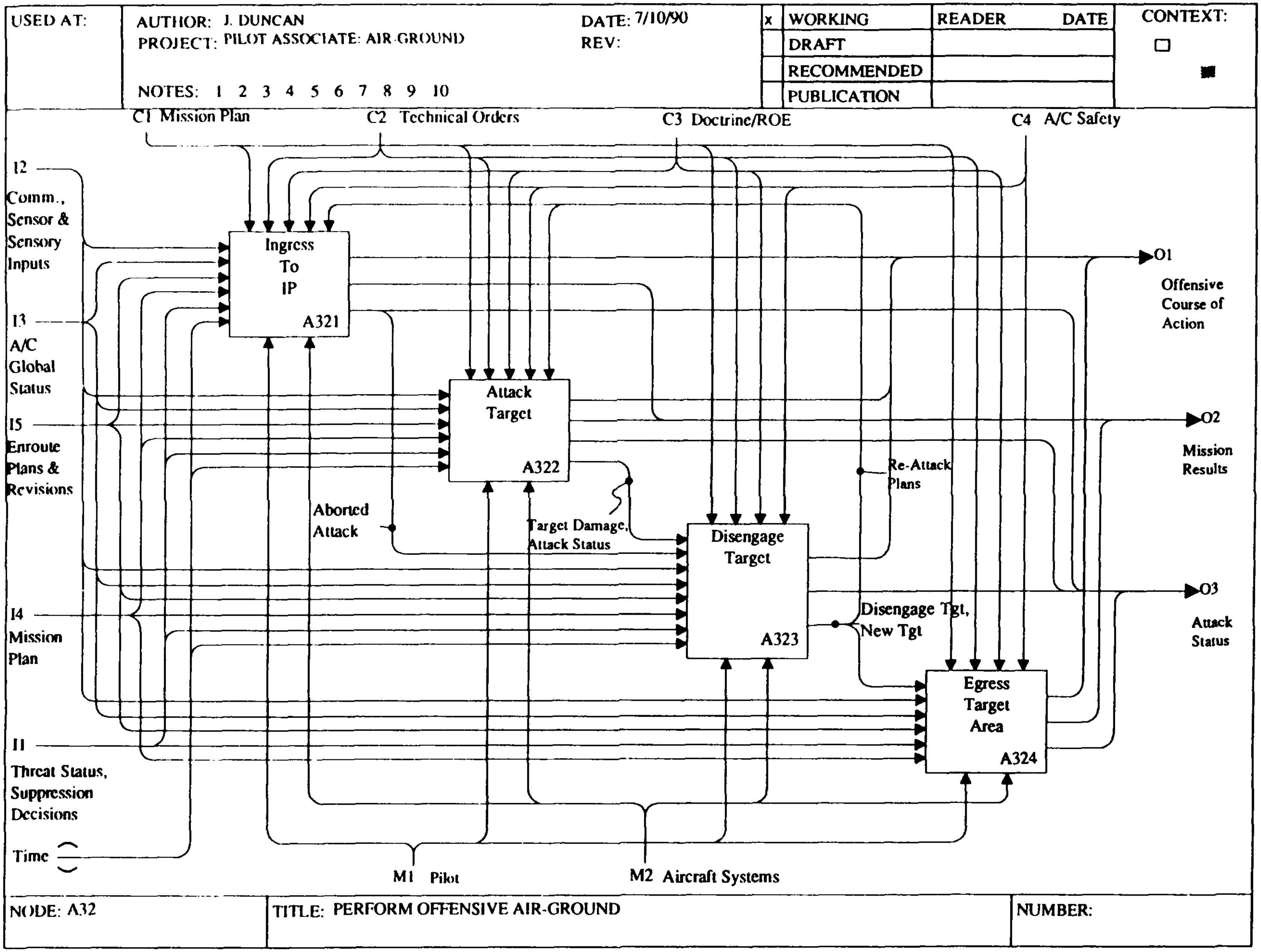
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 A/C Safety
I1 Weapons, Sensors Status
I2 Enroute Plans and Revisions
I4 Comm., Sensor & Sensory Inputs
I5 A/C Global Status
I3 Mission Plan
I6 Threat Status, Suppression Decisions
Acquire Air-Air Target
A3121
Acquisition Status
Execute Air Combat Maneuvers & Tactics
A3122
Ownship vs. Target Position, Energy States
Release Air-Air Weapons
A3123
O1 Attack Status
M1 Pilot
M2 Aircraft Systems
NODE: A312
TITLE: ATTACK AIR-AIR TARGET
NUMBER: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PROJECT: PILOT ASSOCIATE: AIR-GROUND
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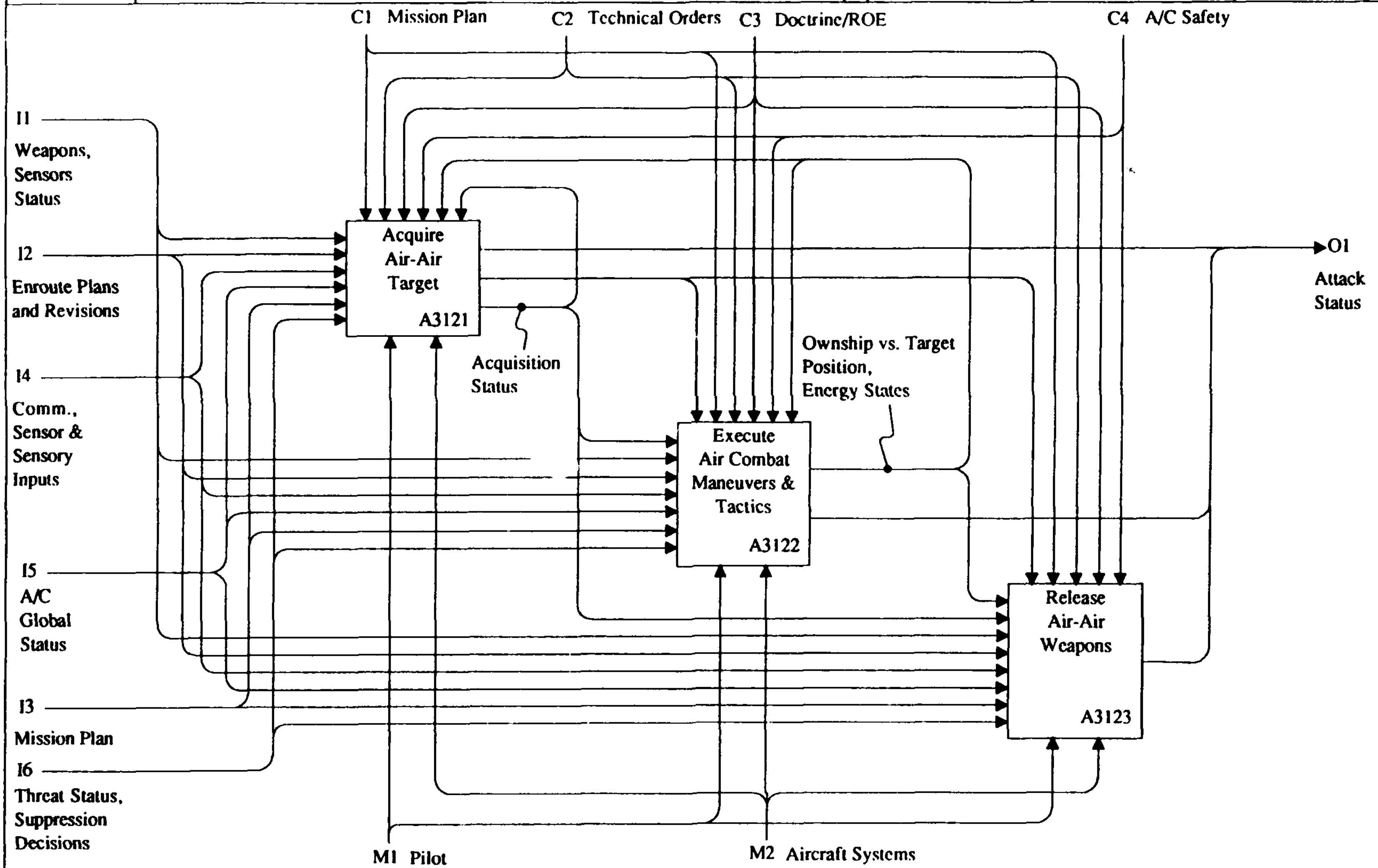
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 A/C Safety
I2
Comm., Sensor & Sensory Inputs
I3
A/C Global Status
I5
Enroute Plans & Revisions
I4
Mission Plan
I1
Threat Status, Suppression Decisions
Time
Ingress To IP
A321
Attack Target
A322
Disengage Target
A323
Egress Target Area
A324
Aborted Attack
Target Damage, Attack Status
Re-Attack Plans
Disengage Tgt, New Tgt
O1
Offensive Course of Action
O2
Mission Results
O3
Attack Status
M1 Pilot
M2 Aircraft Systems
NODE: A32
TITLE: PERFORM OFFENSIVE AIR-GROUND
NUMBER:

USED AT:	AUTHOR: J. DUNCAN PROJECT: PILOT ASSOCIATE: AIR-GROUND NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 7/10/90 REV:	x WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:



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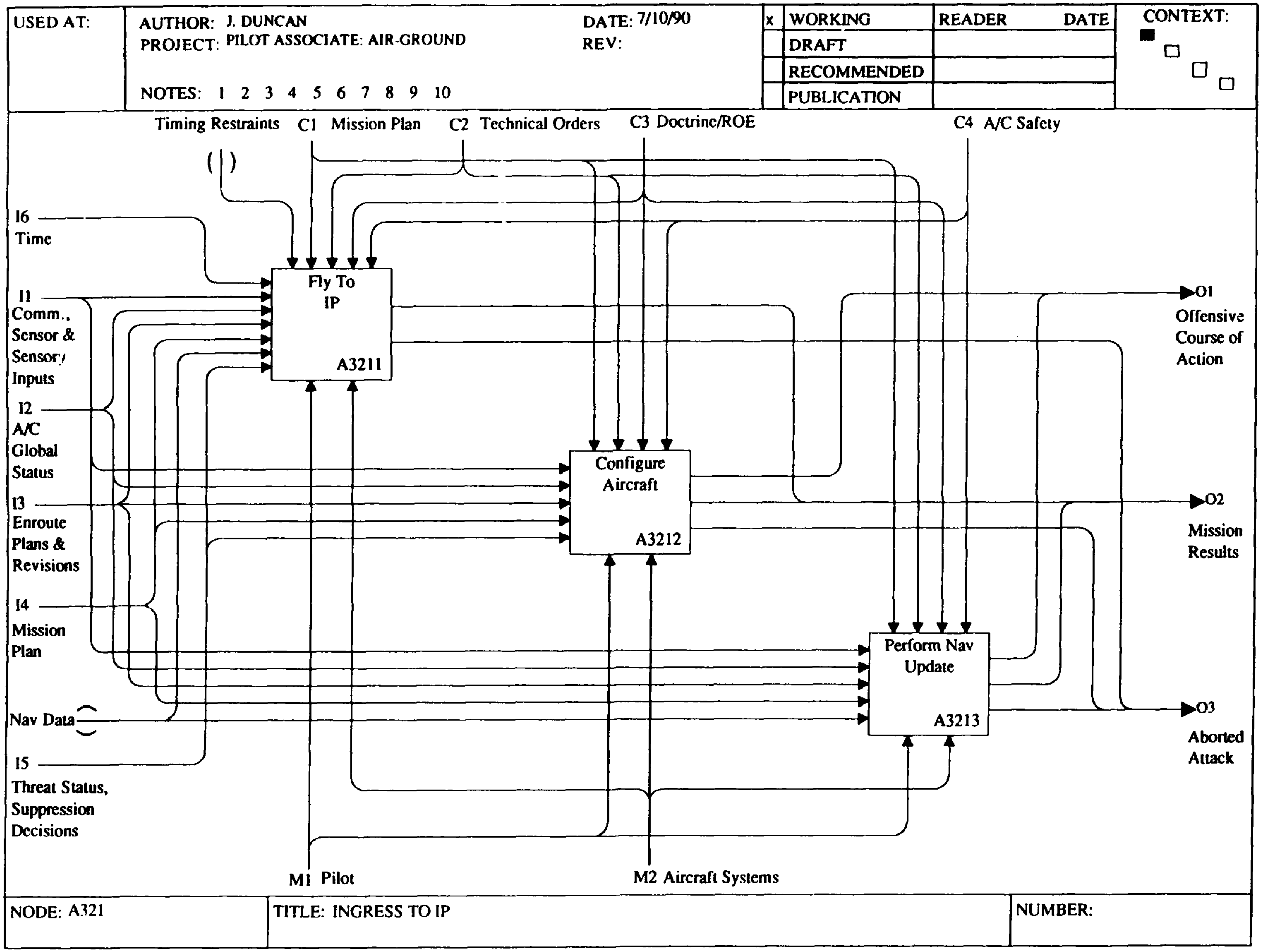

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PROJECT: PILOT ASSOCIATE: AIR-GROUND
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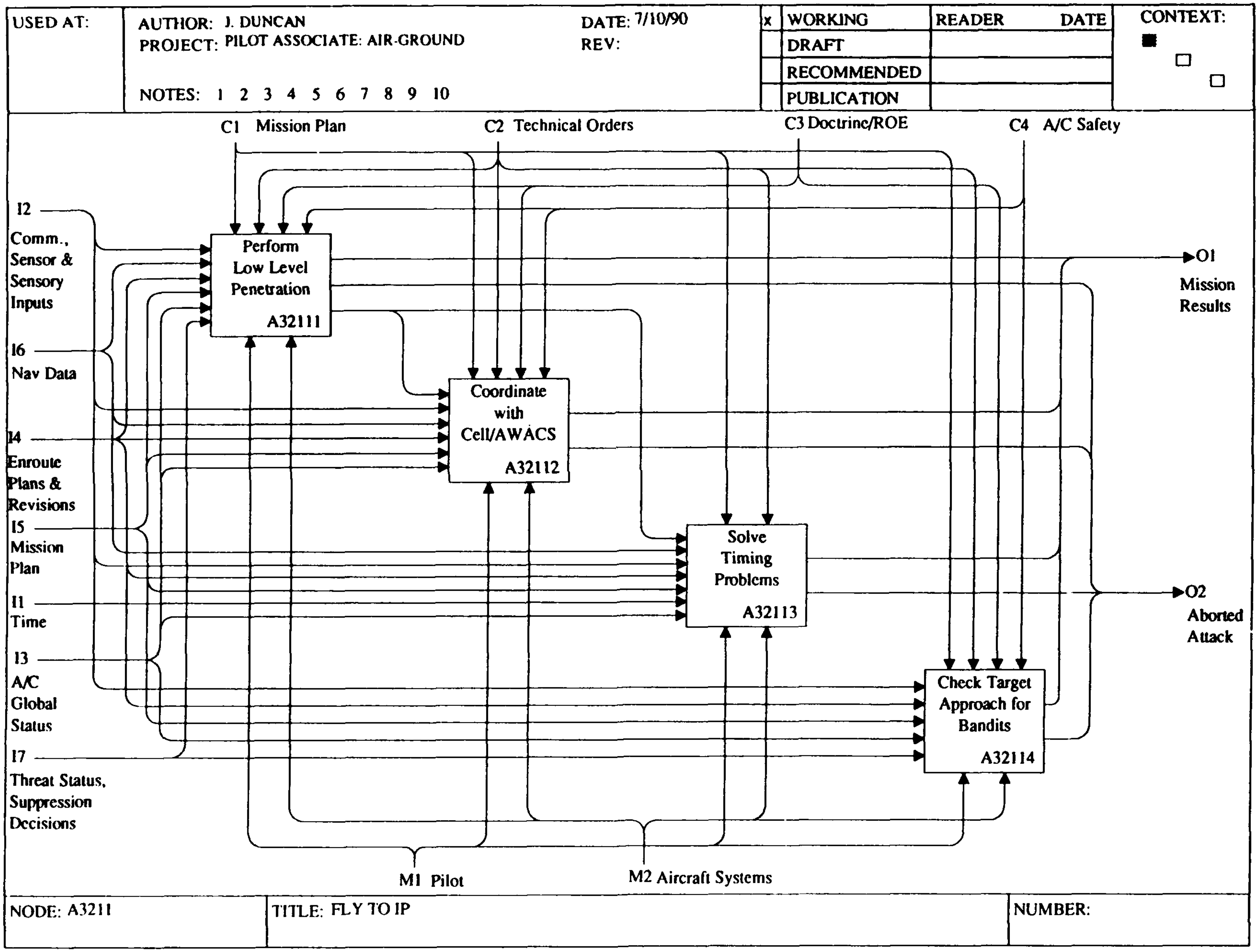
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
Timing Restraints
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 A/C Safety
I6 Time
I1 Comm., Sensor & Sensory Inputs
I2 A/C Global Status
I3 Enroute Plans & Revisions
I4 Mission Plan
Nav Data
I5 Threat Status, Suppression Decisions
Fly To IP
A3211
Configure Aircraft
A3212
Perform Nav Update
A3213
O1 Offensive Course of Action
O2 Mission Results
O3 Aborted Attack
M1 Pilot
M2 Aircraft Systems
NODE: A321
TITLE: INGRESS TO IP
NUMBER: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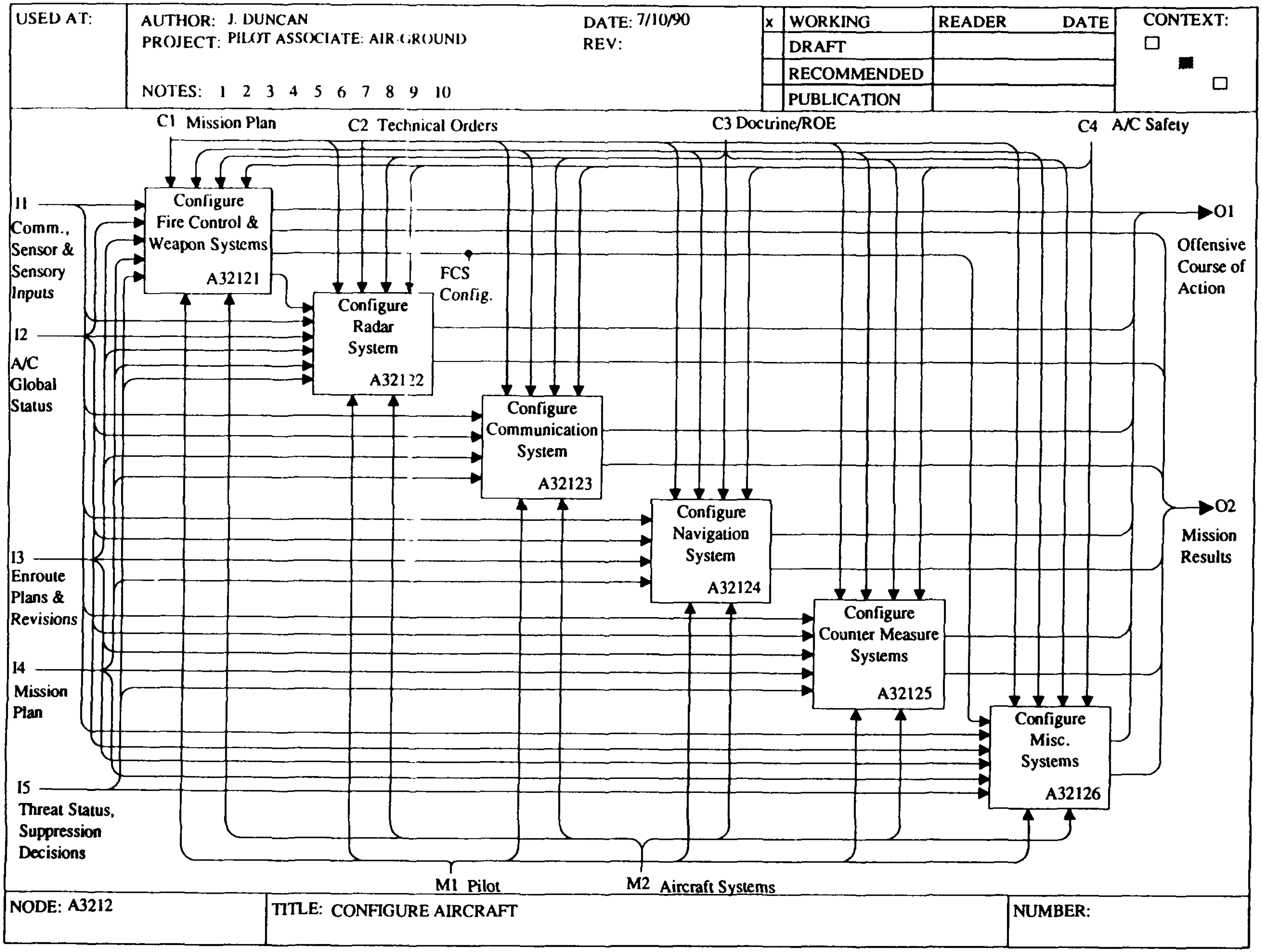
READER
DATE
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 A/C Safety
I2 Comm., Sensor & Sensory Inputs
I6 Nav Data
I4 Enroute Plans & Revisions
I5 Mission Plan
I1 Time
I3 A/C Global Status
I7 Threat Status, Suppression Decisions
Perform Low Level Penetration
A32111
Coordinate with Cell/AWACS
A32112
Solve Timing Problems
A32113
Check Target Approach for Bandits
A32114
O1 Mission Results
O2 Aborted Attack
M1 Pilot
M2 Aircraft Systems
NODE: A3211
TITLE: FLY TO IP
NUMBER: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DATE: 7/10/90
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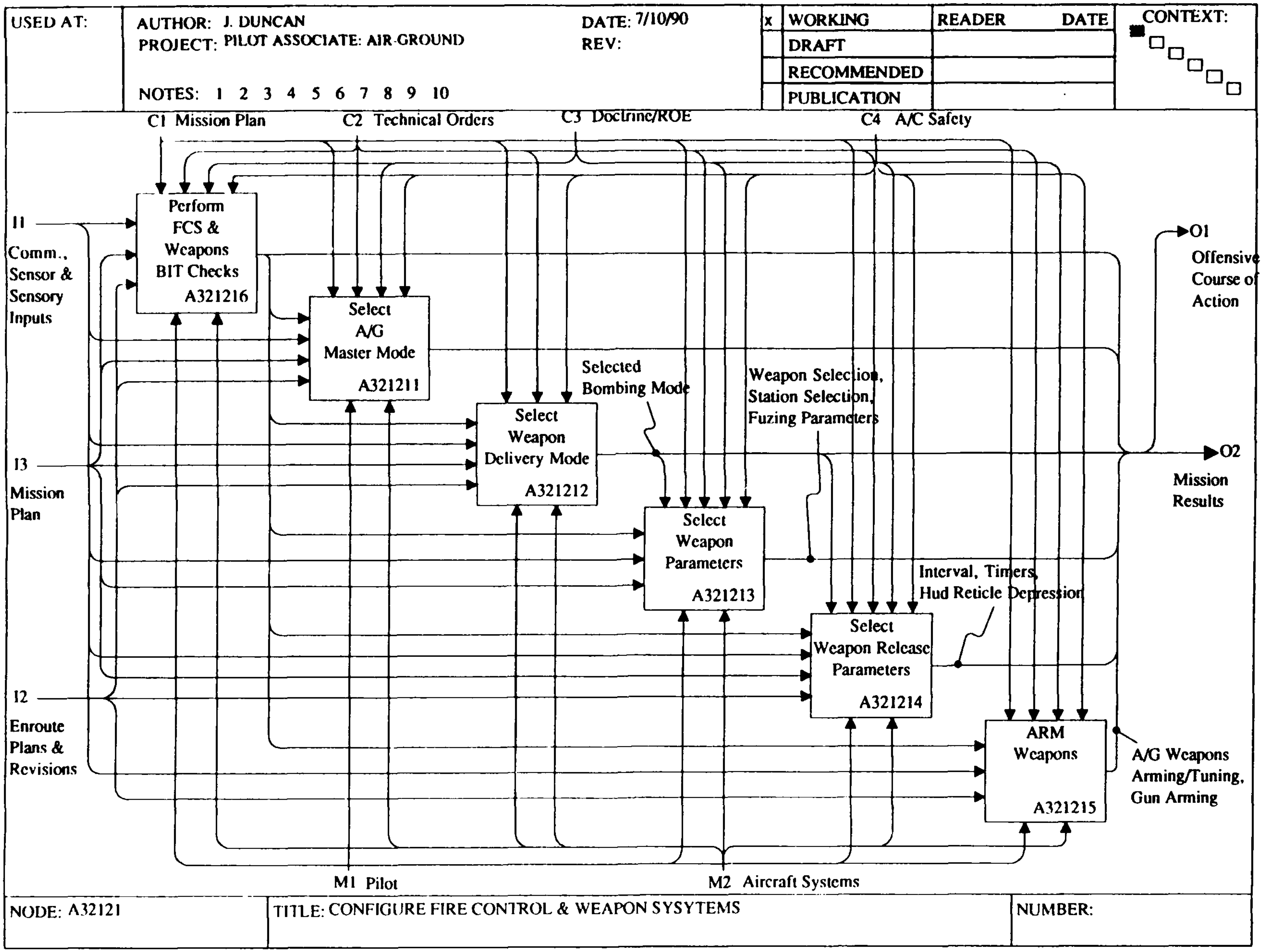
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 A/C Safety
I1 Comm., Sensor & Sensory Inputs
I2 A/C Global Status
I3 Enroute Plans & Revisions
I4 Mission Plan
I5 Threat Status, Suppression Decisions
Configure Fire Control & Weapon Systems A32121
Configure Radar System A32122
FCS Config.
Configure Communication System A32123
Configure Navigation System A32124
Configure Counter Measure Systems A32125
Configure Misc. Systems A32126
O1 Offensive Course of Action
O2 Mission Results
M1 Pilot
M2 Aircraft Systems
NODE: A3212
TITLE: CONFIGURE AIRCRAFT
NUMBER: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PROJECT: PILOT ASSOCIATE: AIR-GROUND
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REV:
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PUBLICATION
READER
DATE
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 A/C Safety
I1 Comm., Sensor & Sensory Inputs
I3 Mission Plan
I2 Enroute Plans & Revisions
Perform FCS & Weapons BIT Checks A321216
Select A/G Master Mode A321211
Select Weapon Delivery Mode A321212
Selected Bombing Mode
Select Weapon Parameters A321213
Weapon Selection, Station Selection, Fuzing Parameters
Select Weapon Release Parameters A321214
Interval, Timers, Hud Reticle Depression
ARM Weapons A321215
A/G Weapons Arming/Tuning, Gun Arming
O1 Offensive Course of Action
O2 Mission Results
M1 Pilot
M2 Aircraft Systems
NODE: A32121
TITLE: CONFIGURE FIRE CONTROL & WEAPON SYSYTEMS
NUMBER:

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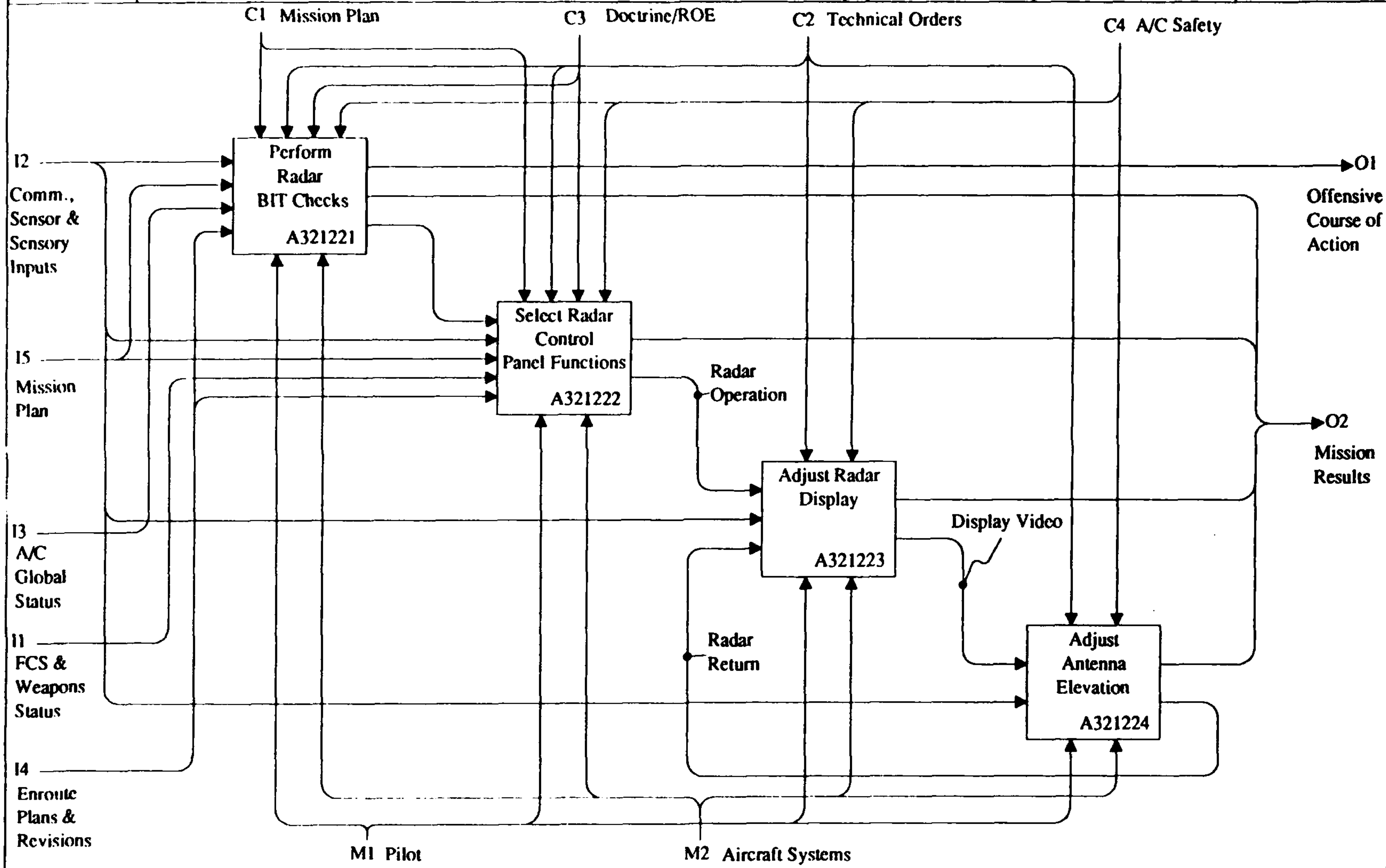

NODE: A32122	TITLE: CONFIGURE RADAR SYSTEM	NUMBER:

USED AT:

AUTHOR: J. DUNCAN
PROJECT: PILOT ASSOCIATE: AIR-GROUND
DATE: 7/10/90
REV:

NOTES: 1 2 3 4 5 6 7 8 9 10

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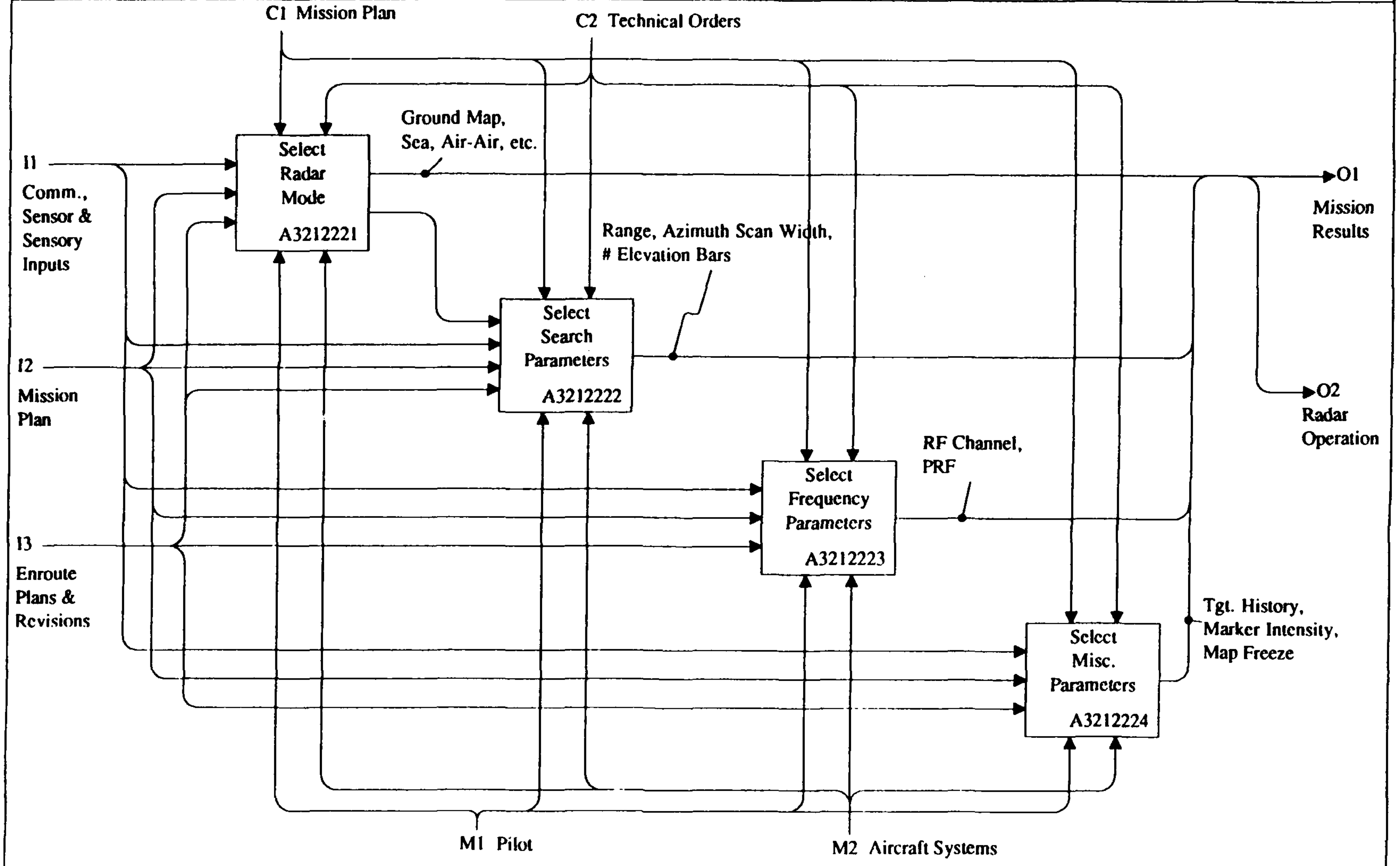

NODE: A321222

TITLE: SELECT RADAR CONTROL PANEL FUNCTIONS

NUMBER:

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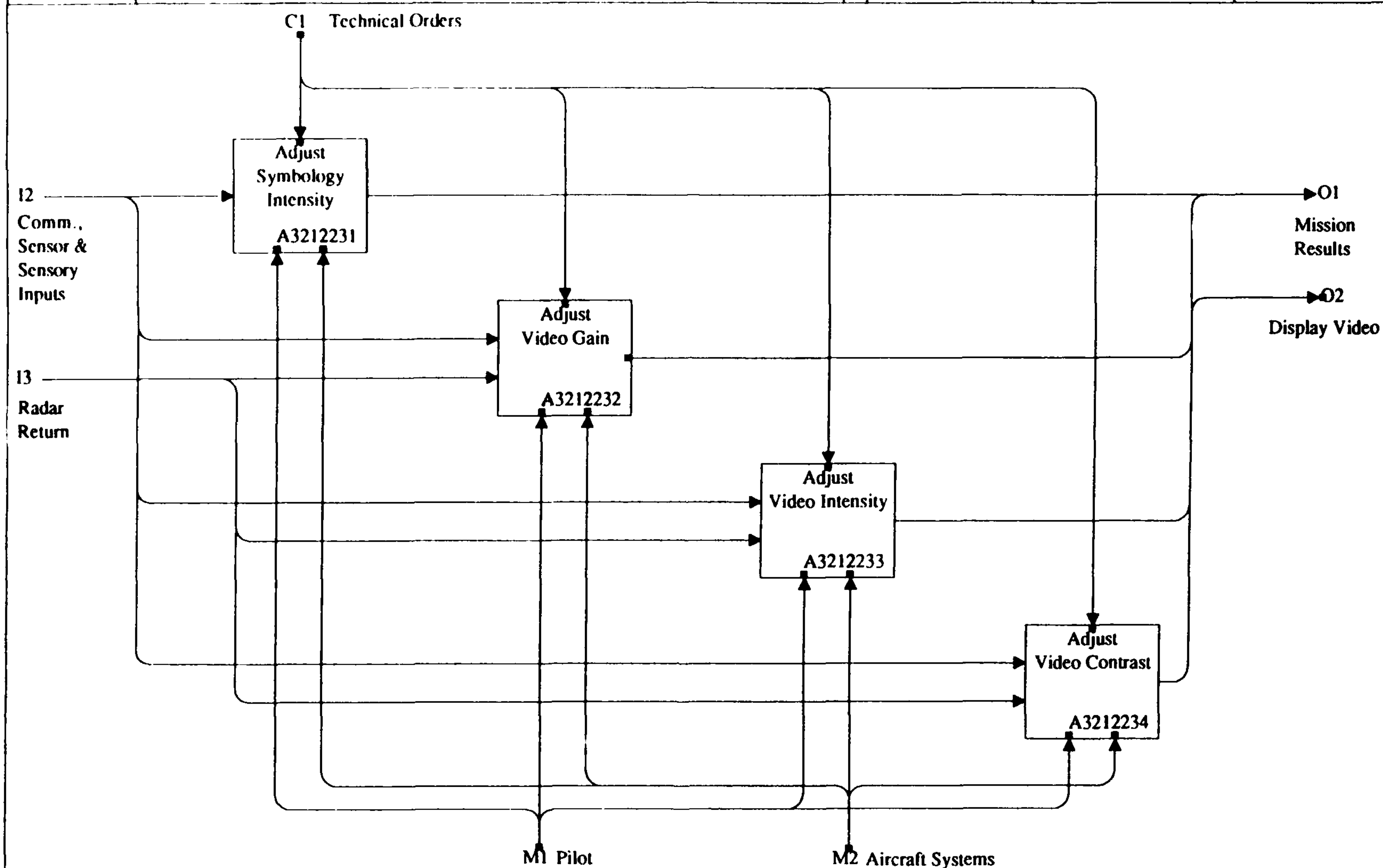

NODE: A321223	TITLE: ADJUST RADAR DISPLAY	NUMBER:

USED AT:	AUTHOR: J. DUNCAN PROJECT: PILOT ASSOCIATE: AIR-GROUND NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 7/10/90 REV:	x	WORKING	READER	DATE	CONTEXT:
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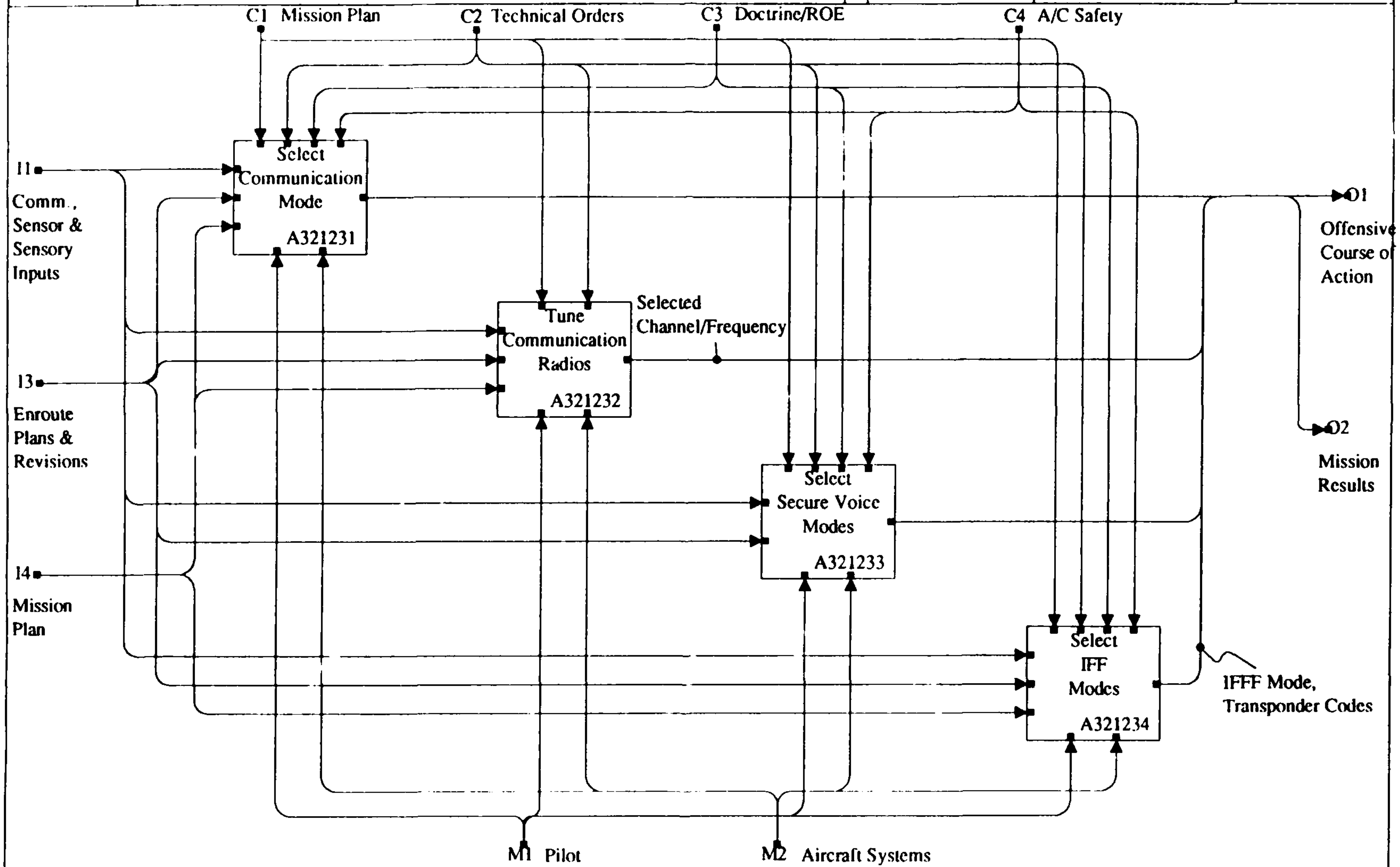
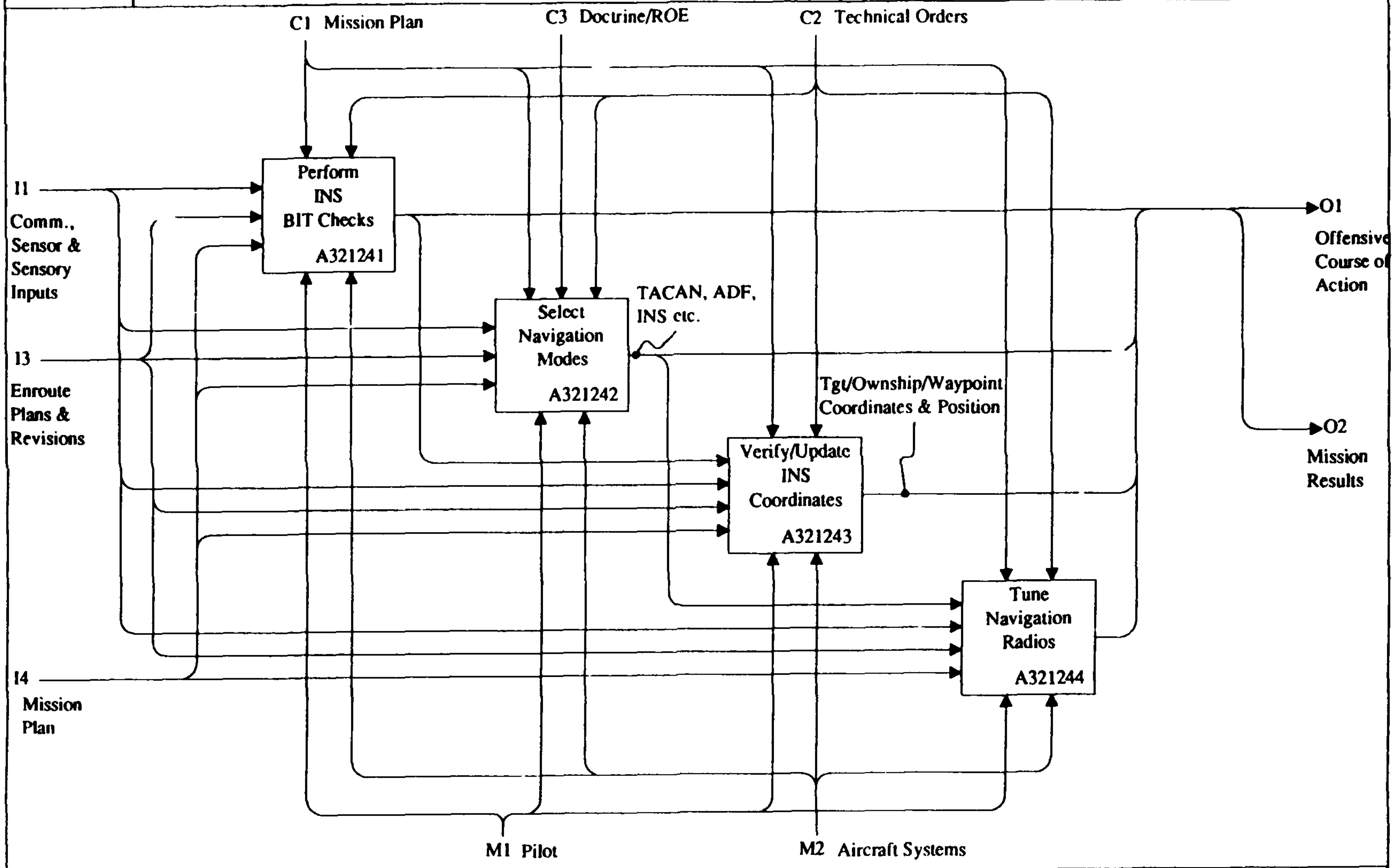


NODE: A32123	TITLE: CONFIGURE COMMUNICATION SYSTEM	NUMBER:

USED AT:	AUTHOR: J. DUNCAN PROJECT: PILOT ASSOCIATE AIR-GROUND NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 7/10/90 REV:	x WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:



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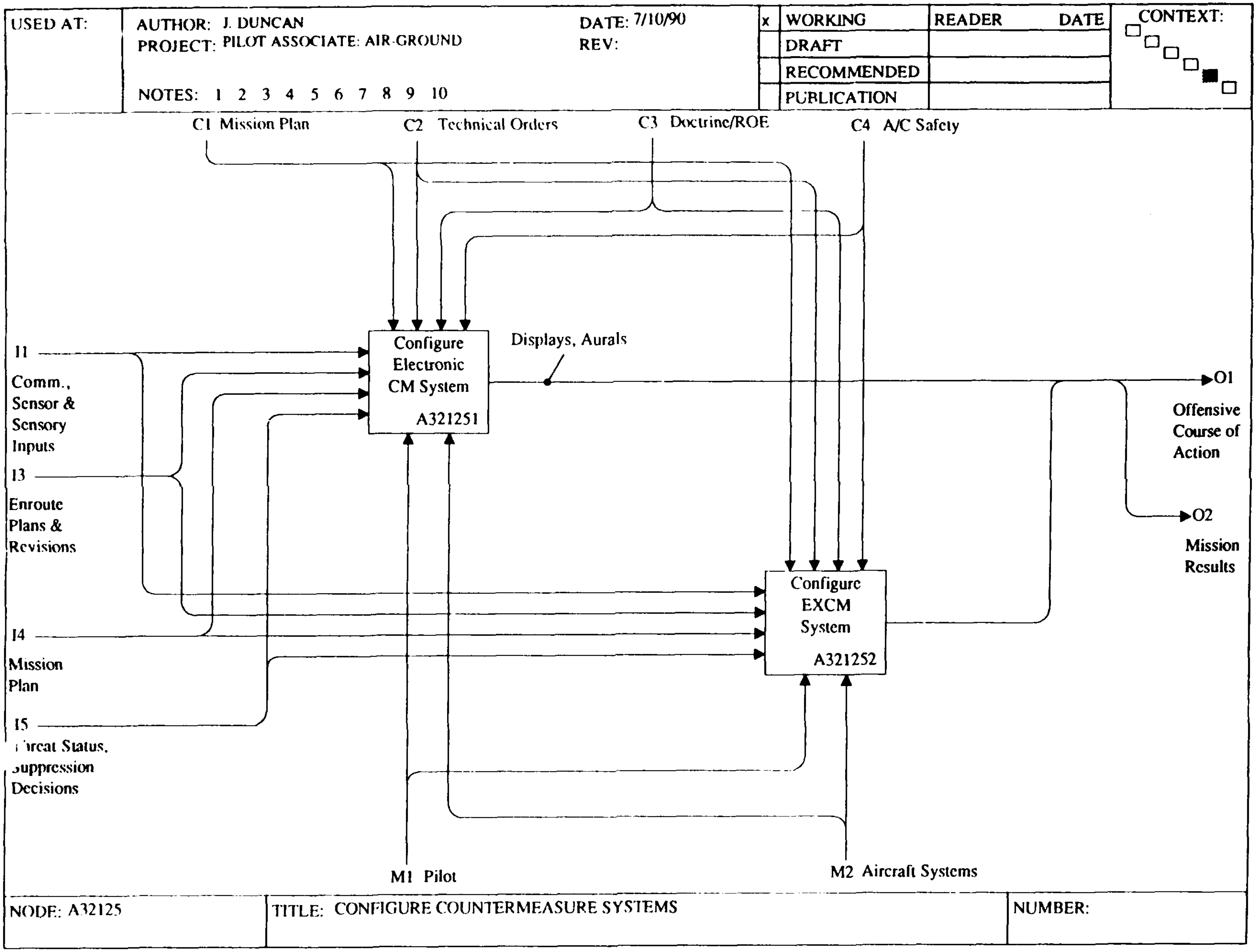
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PROJECT: PILOT ASSOCIATE: AIR-GROUND
DATE: 7/10/90
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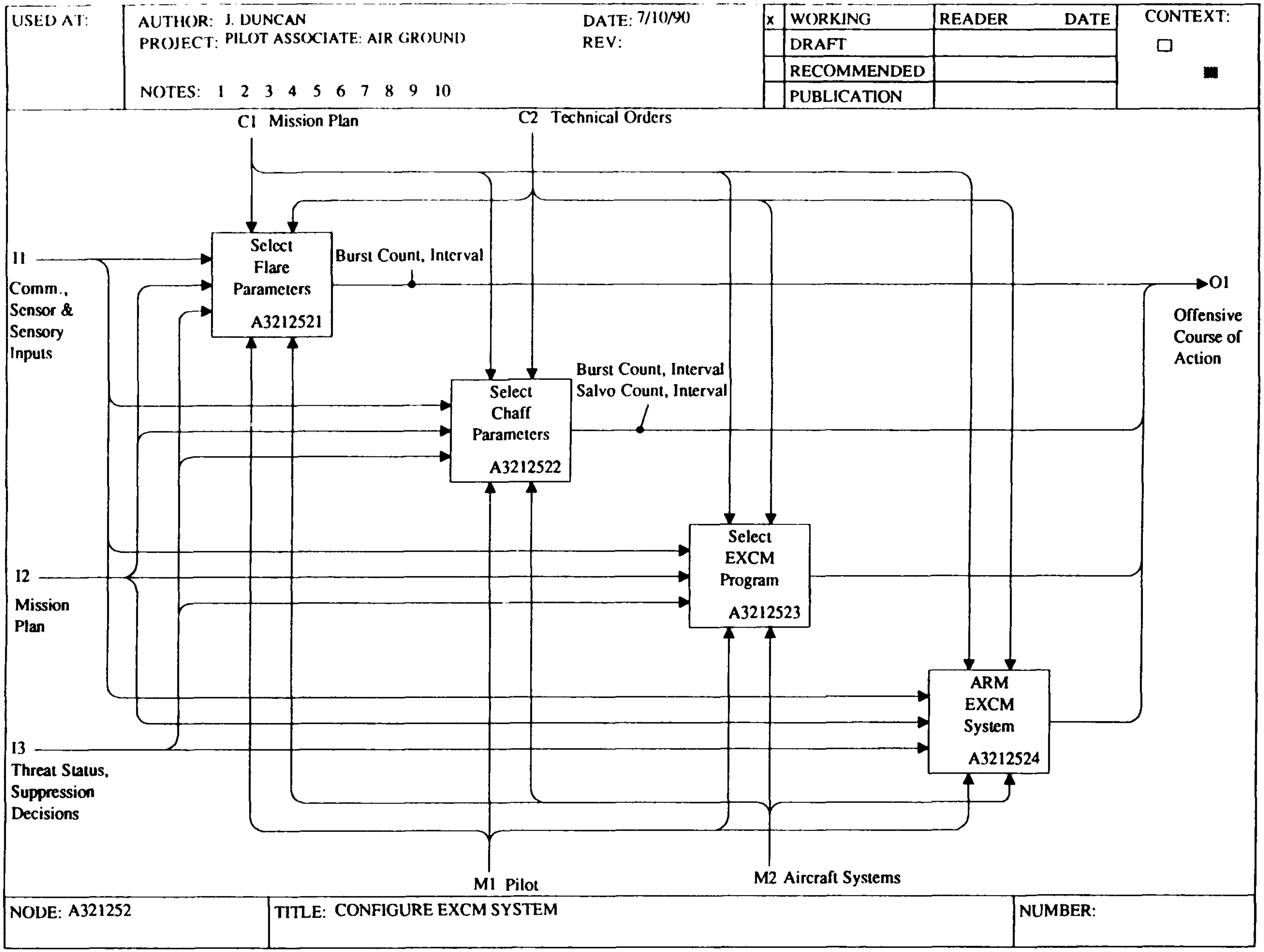
PUBLICATION
READER
DATE
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 A/C Safety
I1 Comm., Sensor & Sensory Inputs
I3 Enroute Plans & Revisions
I4 Mission Plan
I5 Threat Status, Suppression Decisions
Configure Electronic CM System
A321251
Displays, Aurals
Configure EXCM System
A321252
O1 Offensive Course of Action
O2 Mission Results
M1 Pilot
M2 Aircraft Systems
NODE: A32125
TITLE: CONFIGURE COUNTERMEASURE SYSTEMS
NUMBER:



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RECOMMENDED
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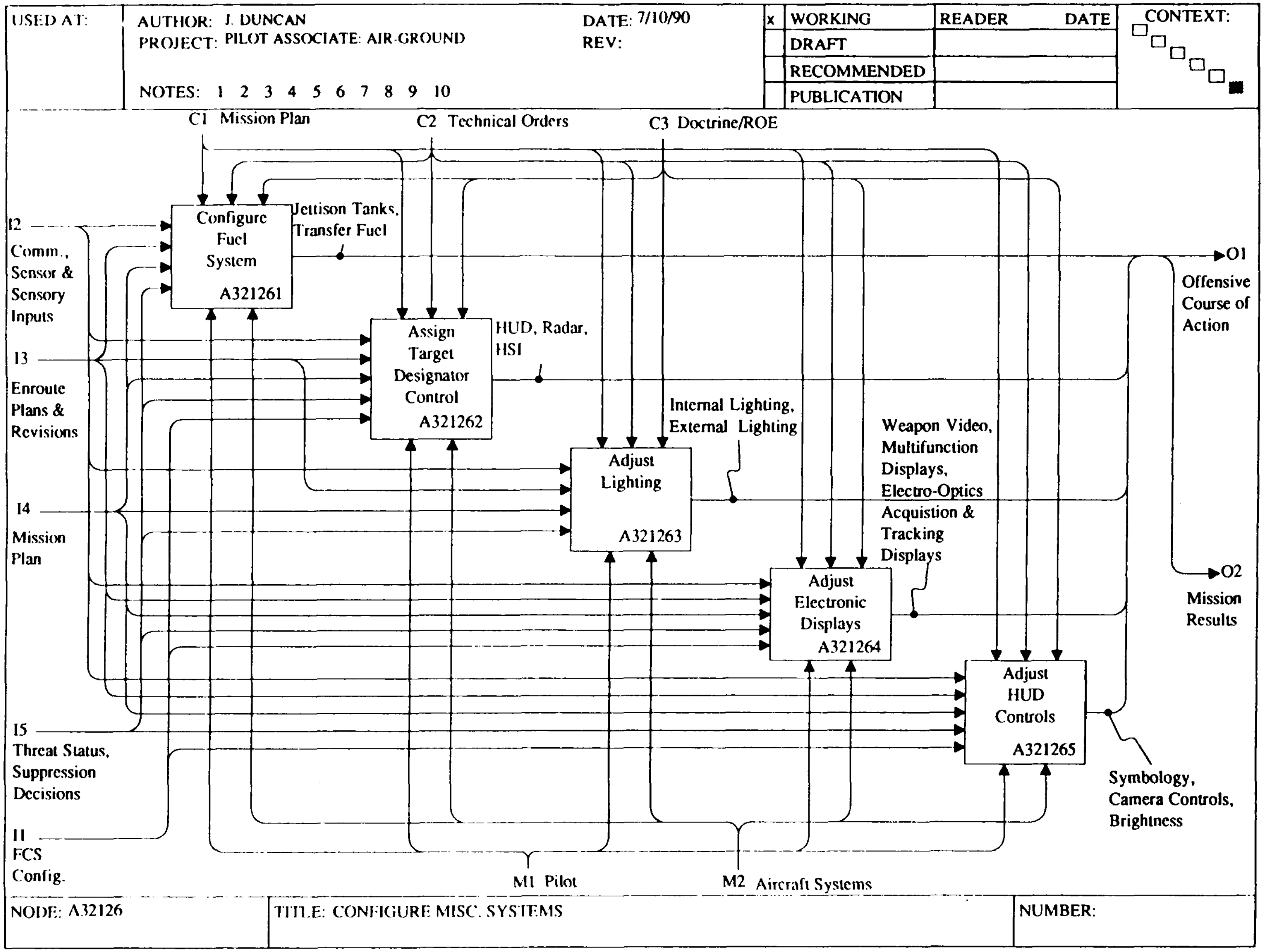
CONTEXT:
C1 Mission Plan
C2 Technical Orders
I1
Comm., Sensor & Sensory Inputs
I2
Mission Plan
I3
Threat Status, Suppression Decisions
Select Flare Parameters
A3212521
Burst Count, Interval
Select Chaff Parameters
A3212522
Burst Count, Interval
Salvo Count, Interval
Select EXCM Program
A3212523
ARM EXCM System
A3212524
O1
Offensive Course of Action
M1 Pilot
M2 Aircraft Systems
NODE: A321252
TITLE: CONFIGURE EXCM SYSTEM
NUMBER: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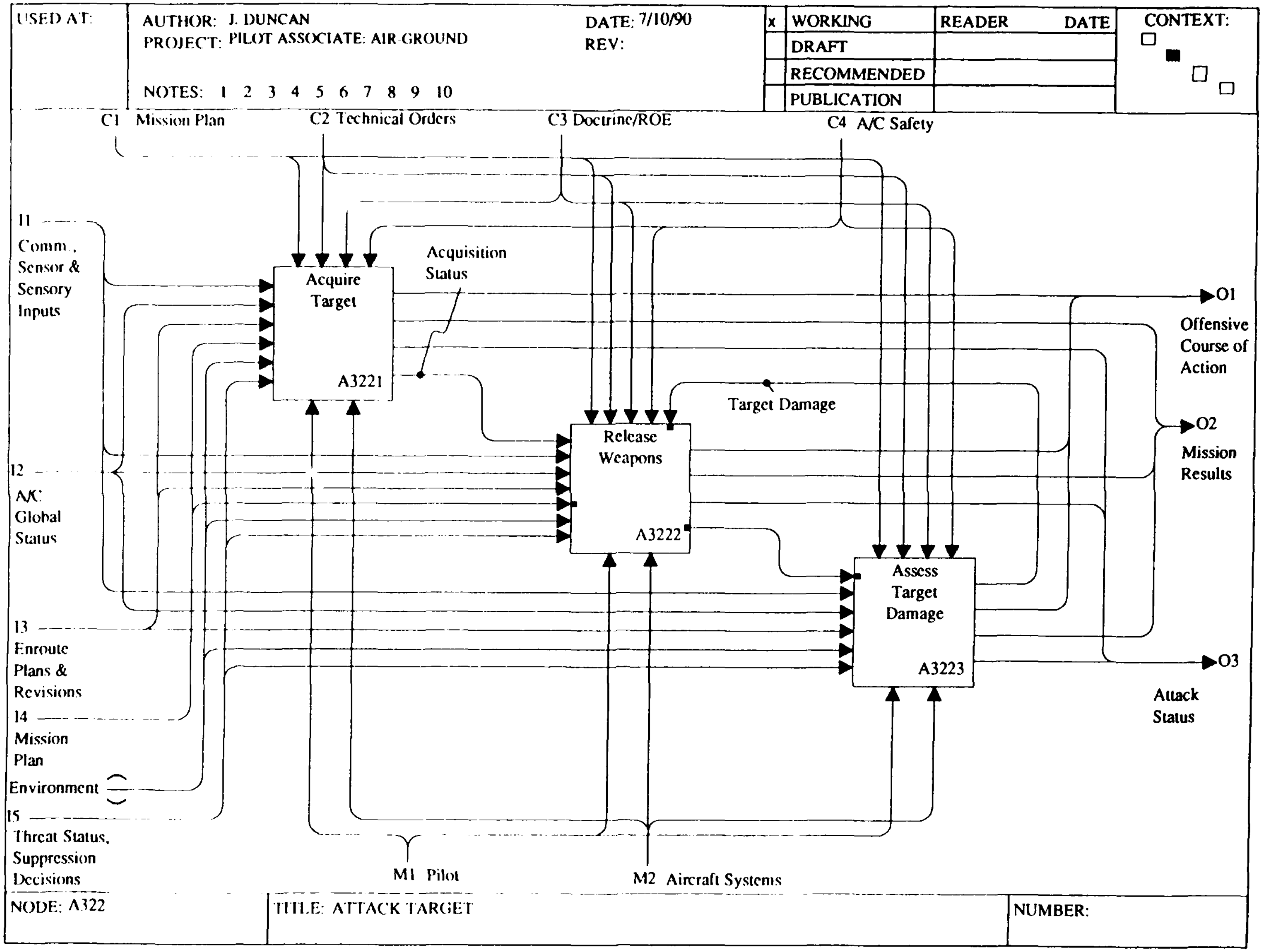
PUBLICATION
READER
DATE
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
I2 Comm., Sensor & Sensory Inputs
I3 Enroute Plans & Revisions
I4 Mission Plan
I5 Threat Status, Suppression Decisions
I1 FCS Config.
Configure Fuel System
A321261
Jettison Tanks, Transfer Fuel
Assign Target Designator Control
A321262
HUD, Radar, HSI
Adjust Lighting
A321263
Internal Lighting, External Lighting
Adjust Electronic Displays
A321264
Weapon Video, Multifunction Displays, Electro-Optics Acquistion & Tracking Displays
Adjust HUD Controls
A321265
Symbology, Camera Controls, Brightness
O1 Offensive Course of Action
O2 Mission Results
M1 Pilot
M2 Aircraft Systems
NODE: A32126
TITLE: CONFIGURE MISC. SYSTEMS
NUMBER:



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DATE: 7/10/90
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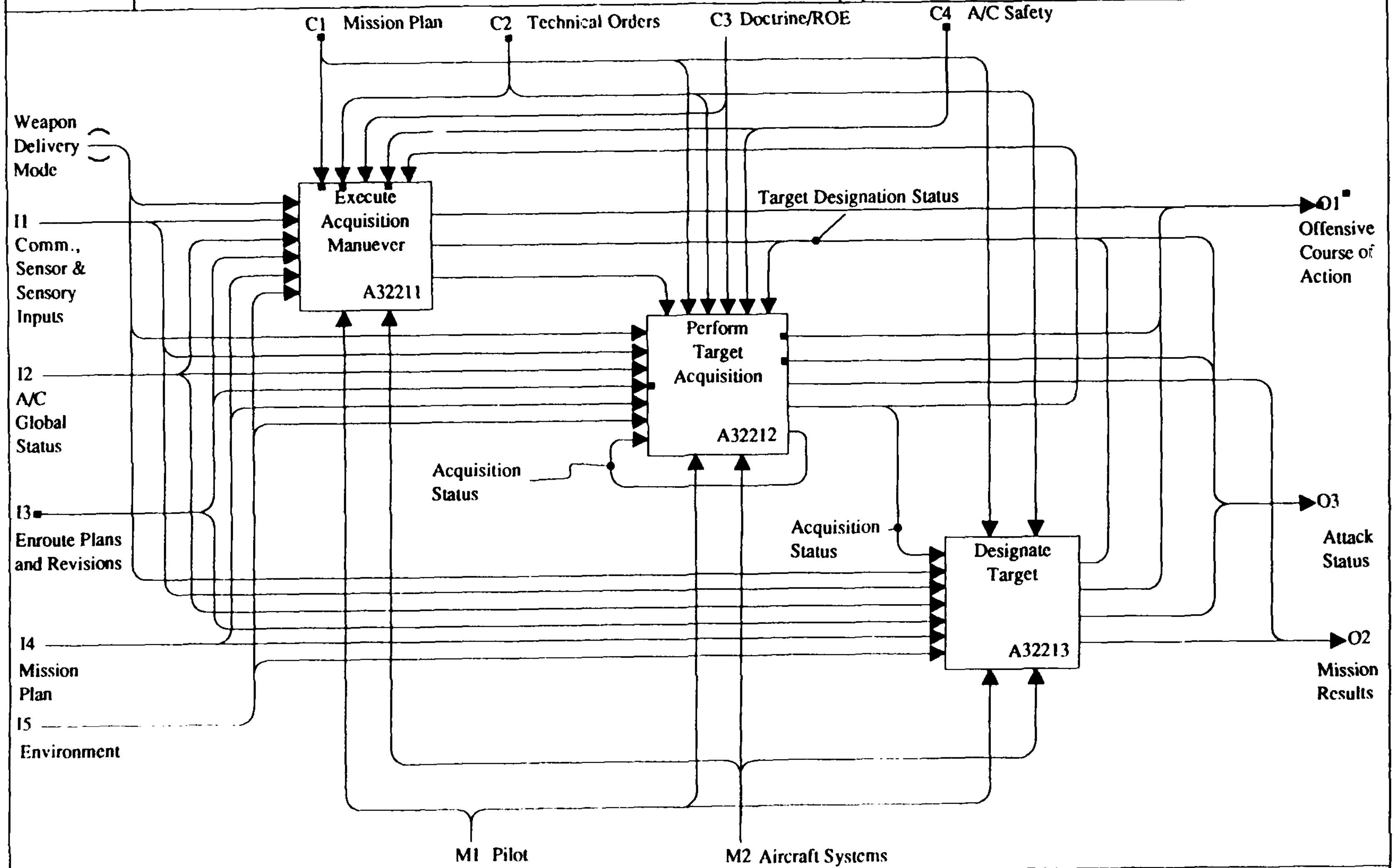
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 A/C Safety
I1 Comm., Sensor & Sensory Inputs
I2 A/C Global Status
I3 Enroute Plans & Revisions
I4 Mission Plan
Environment
I5 Threat Status, Suppression Decisions
Acquire Target
A3221
Acquisition Status
Release Weapons
A3222
Target Damage
Assess Target Damage
A3223
O1 Offensive Course of Action
O2 Mission Results
O3 Attack Status
M1 Pilot
M2 Aircraft Systems
NODE: A322
TITLE: ATTACK TARGET
NUMBER:

USED AT:	AUTHOR: J. DUNCAN PROJECT: PILOT ASSOCIATE: AIR-GROUND NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 7/10/90 REV:	x WORKING DRAFT RECOMMENDED PUBLICATION	READER	DATE	CONTEXT:



NODE: A3221	TITLE: ACQUIRE TARGET	NUMBER:

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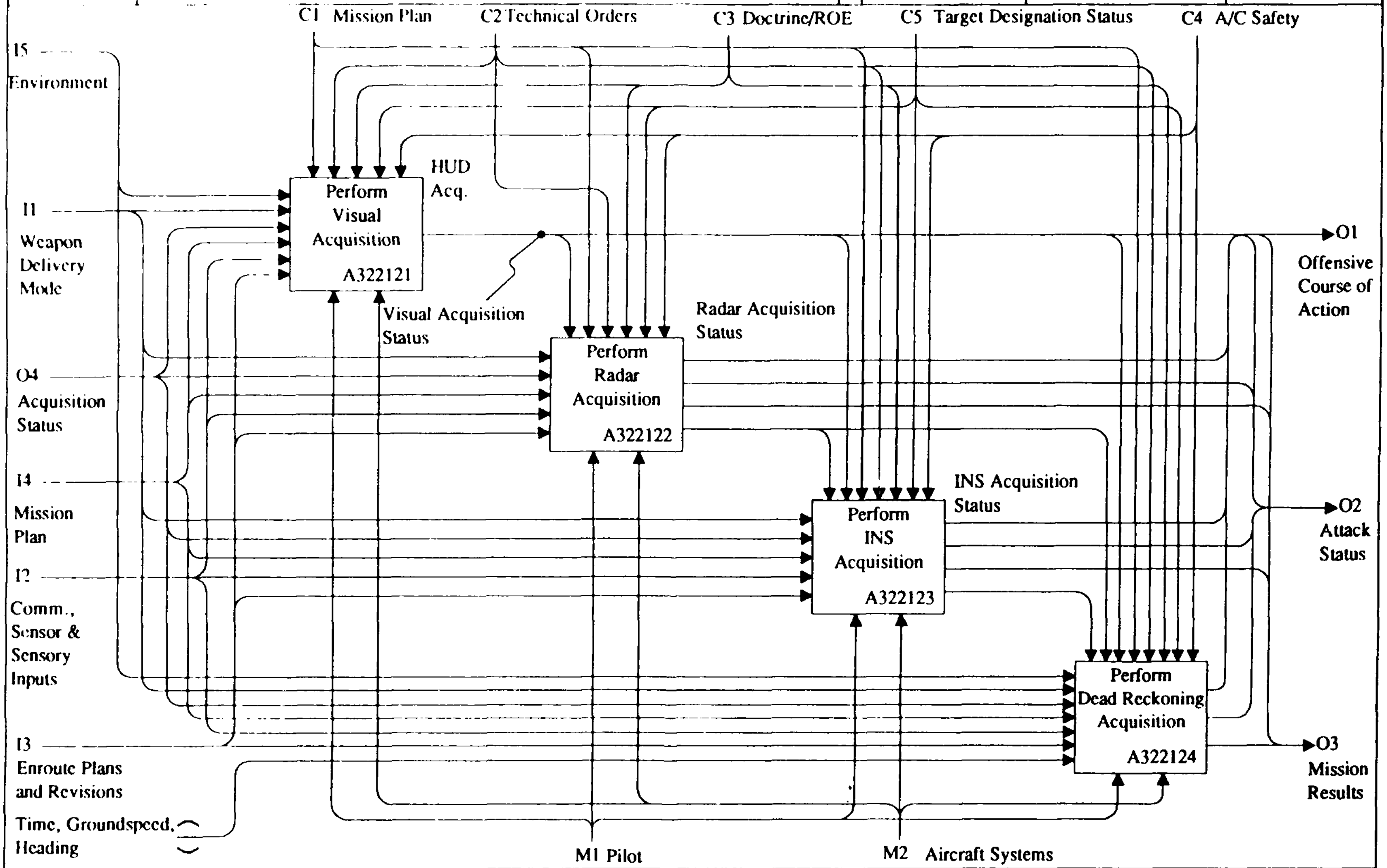

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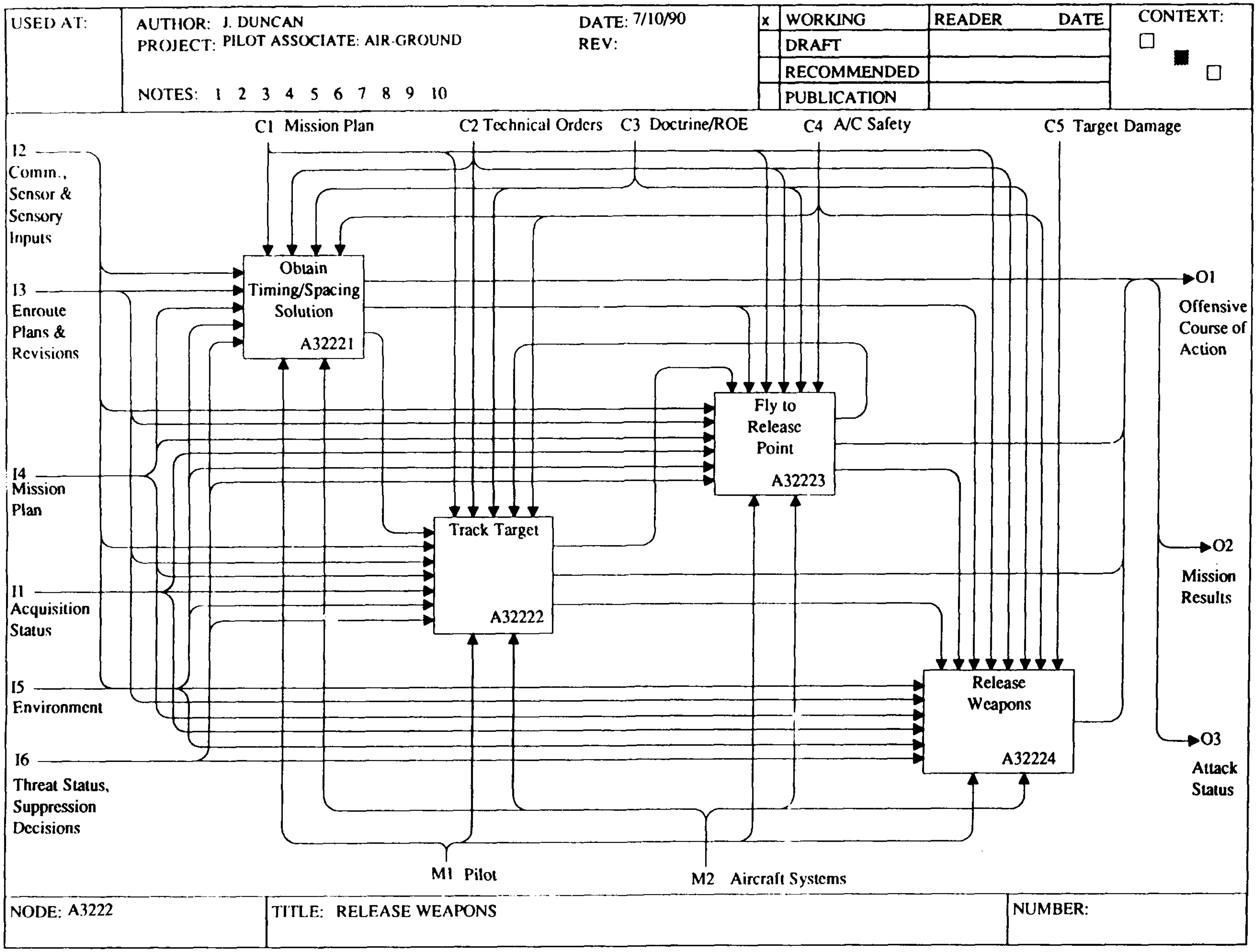
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DATE: 7/10/90
REV:
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DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
C1 Mission Plan
C2 Technical Orders
C3 Doctrine/ROE
C4 A/C Safety
C5 Target Damage
I2 Comm., Sensor & Sensory Inputs
I3 Enroute Plans & Revisions
I4 Mission Plan
I1 Acquisition Status
I5 Environment
I6 Threat Status, Suppression Decisions
Obtain Timing/Spacing Solution
A32221
Track Target
A32222
Fly to Release Point
A32223
Release Weapons
A32224
O1 Offensive Course of Action
O2 Mission Results
O3 Attack Status
M1 Pilot
M2 Aircraft Systems
NODE: A3222
TITLE: RELEASE WEAPONS
NUMBER:

USED AT:	AUTHOR: J. DUNCAN PROJECT: PILOT ASSOCIATE: AIR-GROUND NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 7/10/90 REV:	x	WORKING	READER	DATE	CONTEXT:
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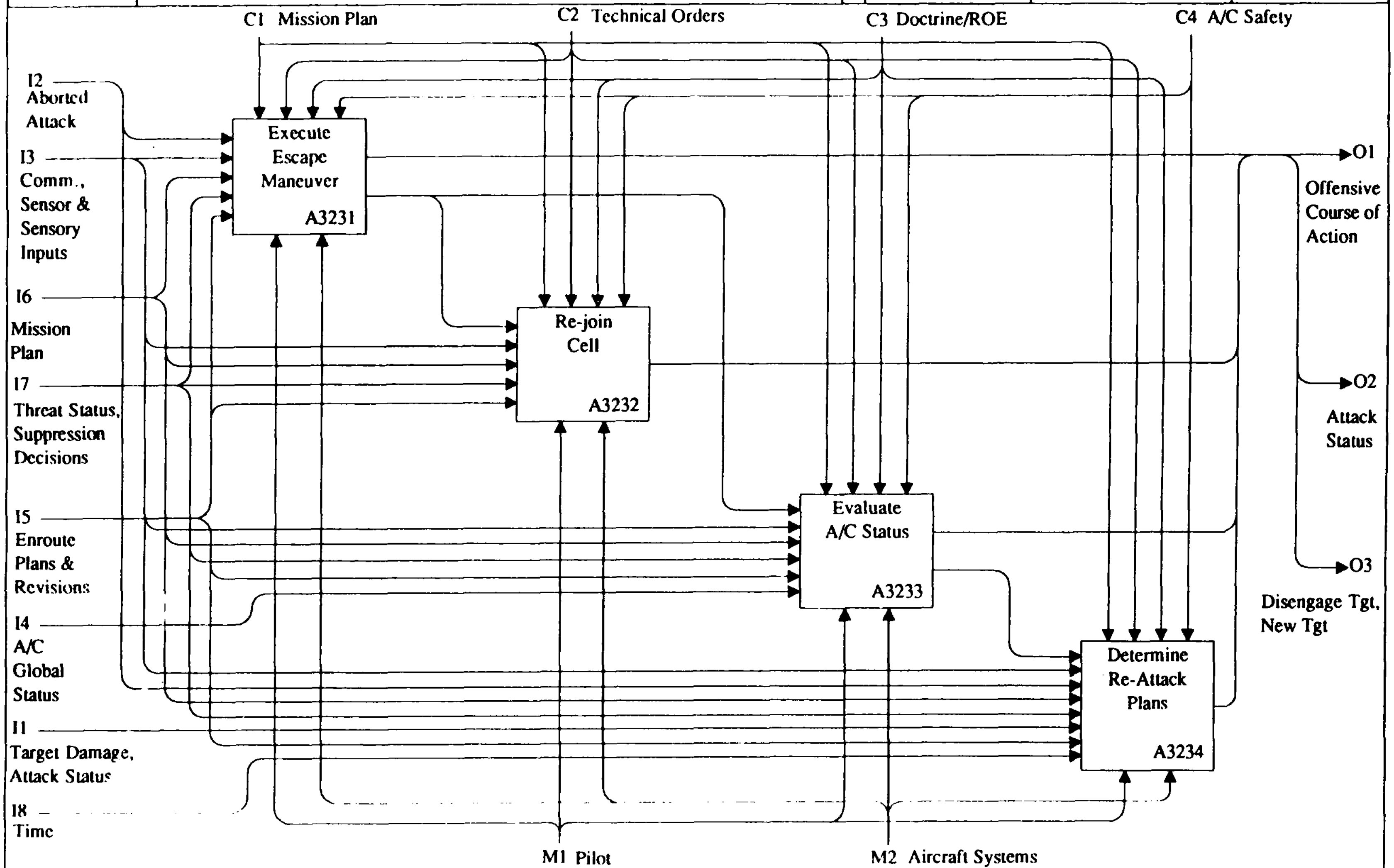

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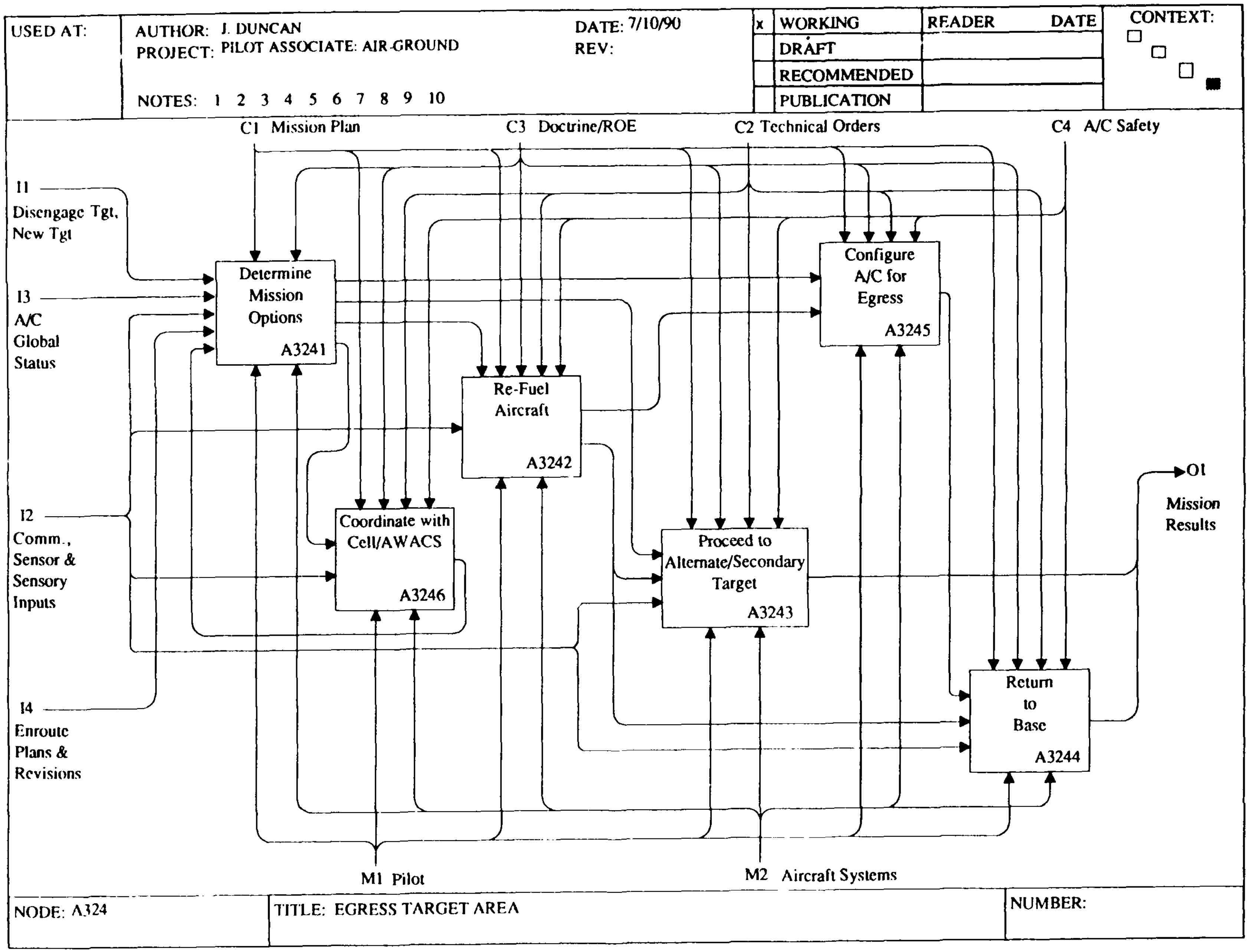
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DATE: 7/10/90
REV:
NOTES: 1 2 3 4 5 6 7 8 9 10
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DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
C1 Mission Plan
C3 Doctrine/ROE
C2 Technical Orders
C4 A/C Safety
I1 Disengage Tgt, New Tgt
I3 A/C Global Status
I2 Comm., Sensor & Sensory Inputs
I4 Enroute Plans & Revisions
Determine Mission Options A3241
Re-Fuel Aircraft A3242
Coordinate with Cell/AWACS A3246
Proceed to Alternate/Secondary Target A3243
Configure A/C for Egress A3245
Return to Base A3244
O1 Mission Results
M1 Pilot
M2 Aircraft Systems
NODE: A324
TITLE: EGRESS TARGET AREA
NUMBER:

USED AT:	AUTHOR: J. DUNCAN PROJECT: PILOT ASSOCIATE: AIR-GROUND NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 7/10/90 REV:	x	WORKING	READER	DATE	CONTEXT:
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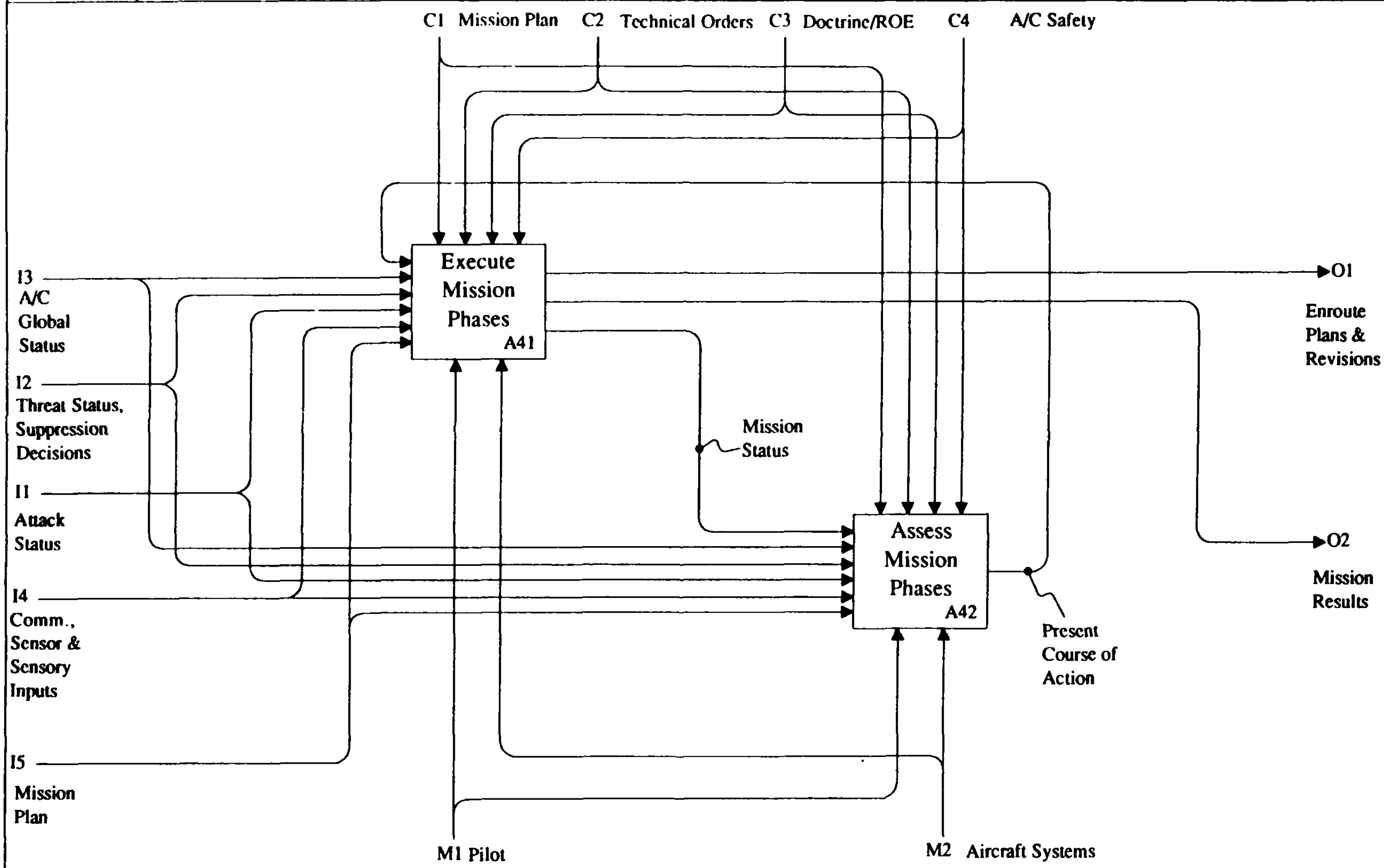

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USED AT:	AUTHOR: J. DUNCAN PROJECT: PILOT ASSOCIATE: AIR GROUND NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 7/10/90 REV:	x	WORKING	READER	DATE	CONTEXT:
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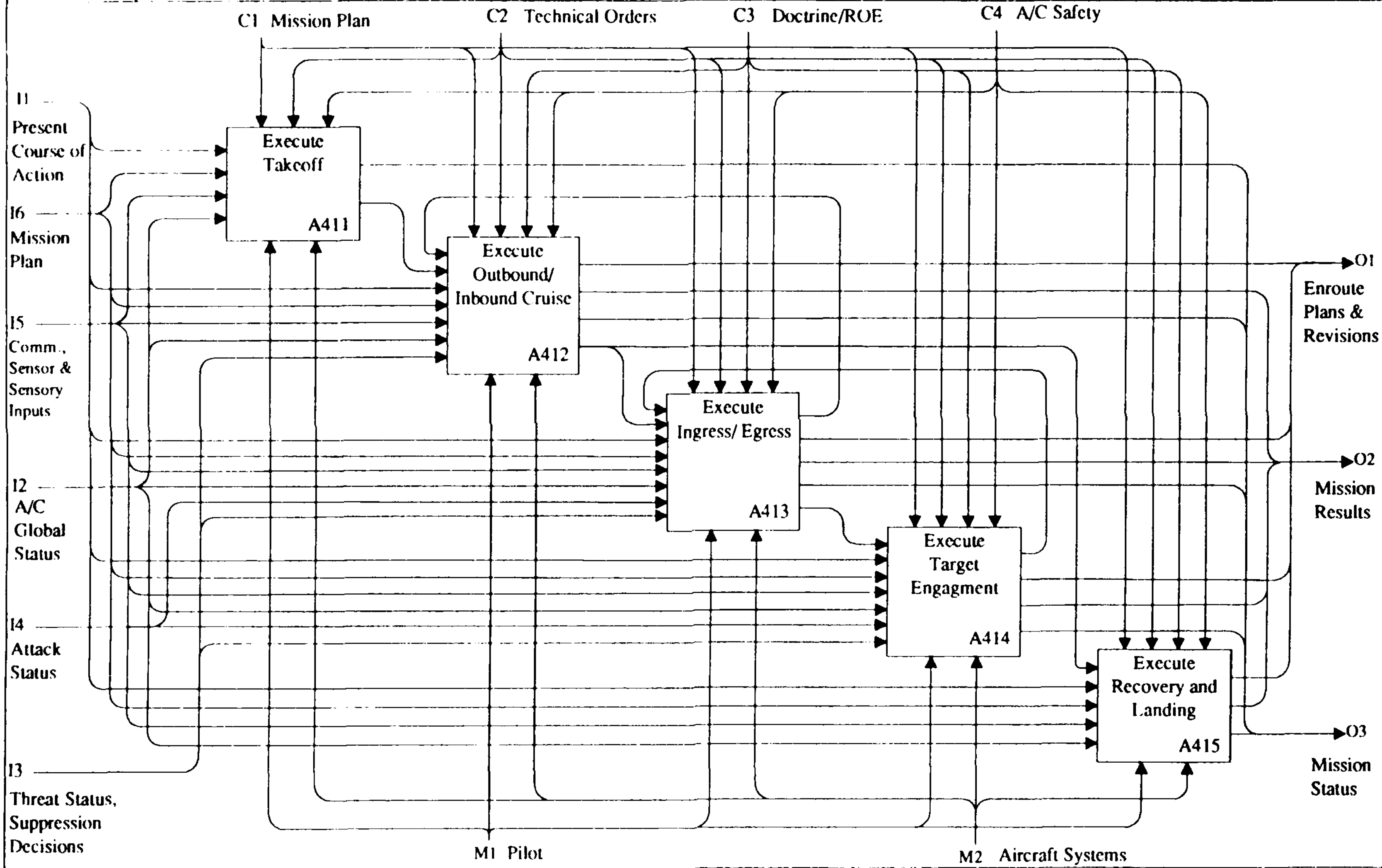

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USED AT:	AUTHOR: J. DUNCAN PROJECT: PILOT ASSOCIATE: AIR-GROUND NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 7/10/90 REV:	x	WORKING	READER	DATE	CONTEXT:
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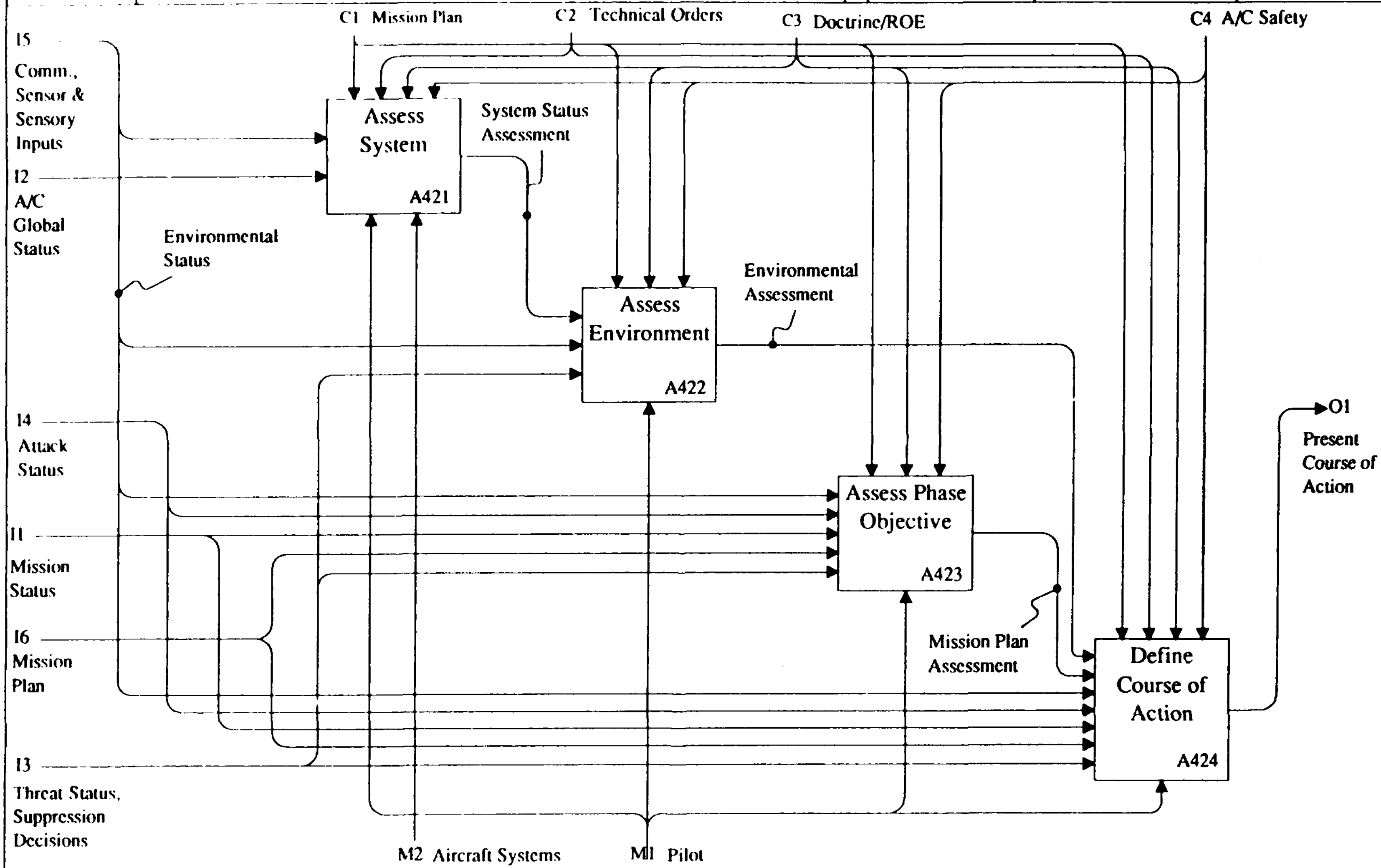


NODE: A42	TITLE: ASSESS MISSION PHASES	NUMBER:

APPENDIX C

$IDEF_0$ DATA DICTIONARY

APPENDIX C

IDEF DATA DICTIONARY - TACTICAL AIR-GROUND MISSION

The IDEF Tactical Air-Ground Mission comprises a pilot oriented model of an air-ground mission for use in analysis of the pilot tasks, performance and information requirements necessary to accomplish the mission. An emphasis is placed on the associated mission functions occurring during the ingress to the target IP phase, the target attack phase, and the egress phase. The model is based on mission performance by an F-16 type aircraft with CCIP and CCRP weapon delivery modes and comparable aircraft fire control, radar, and related weapon systems accuracy and capabilities.

The IDEF Data Dictionary provides definitions for each function within the IDEF Tactical Air-Ground Mission decomposition and unique Inputs, Outputs, Controls/Constraints, and performance Mechanisms are described. A description of pertinent parameters is provided for those functions requiring elaboration.

A-0 PERFORM TACTICAL AIR-GROUND MISSION

This function represents the performance of a Tactical Air-to-Ground Mission. The various functional parameters represent the top level requirements for aircraft operation and mission performance for all aspects of the mission.

INPUTS

I1 Communications, Sensor & Sensory Inputs

Inputs obtained by the pilot via one or more of the five human senses : sight, touch, taste, smell and hearing. For the Tactical Air-Ground Mission these include visual, aural, touch, acceleration forces, vibration, and physiological inputs to the pilot.

I2 Mission Plan

The overall design, method, or scheme for accomplishing the Tactical Air-Ground Mission to attain the mission objective.

MECHANISMS

M1 Pilot

Experienced, combat ready, aircrew position rated, USAF flight personnel responsible for performing the tactical air-ground mission. Mission pilot task performance based on current ability and capabilities due to physiological condition as affected by G loads, illness, fatigue, and incapacity due to chemical exposure effects and wounds.

M2 Aircraft Systems

The combination of components - such as the flight, propulsion, navigation, defensive, and other applicable aircraft systems - which function as an integrated system to accomplish the mission at an acceptable level of risk and pilot workload. Includes aircraft capabilities as affected by systems configuration, fuel and stores state, malfunctions, battle damage, system performance levels and aircraft energy state.

OUTPUTS

O1 Mission Results

The cumulative status (i.e. aircraft position, systems operations/malfunctions, target acquisition and engagement, weapon effects) of each of the mission segments throughout the mission. Individual actions, conditions, and events that culminate in the total mission effectiveness measures of target disposition and aircraft survivability.

CONTROLS

C1 Mission Plan

The overall design, method, or scheme for accomplishing the Tactical Air-to-Ground Mission and to attain mission objectives. Includes the flight route, planned procedures, alternate actions, mission goals and other information and parameters pertinent to the mission.

Mission Considerations

- Minimize Exposure Time
  - Limit Real Time Tasks During Attack Phase

- Maximize Terrain Obscuration
- Limit Pop-up/Egress Altitude
- Minimize Altitude
- Maximize Airspeed

Maintain Situation Awareness
- Aircraft Status
- Aircraft Position
- Terrain, Obstacle Clearance
- Target Location
- Threat Location & Status
- Attack Package Locations

Defensive Response to Chemicals

Attack Package
- Size, Mix
  - Target Type
  - Level of Damage Required
  - Anticipated Threat
  - Asset Availability
  - Expense
  - Required Support
- Communications
- Formation, Spacing Requirements
- Delivery Tactics
  - Release Points
  - Frag Damage
  - Spacing
  - Attack Sequence, Coordination
  - Mutual Support

Target Parameters/Characteristics
- Target Features
- Location - Latitude, Longitude, Elevation
- Orientation, Spacing
- Surrounding Terrain
- Anticipated Defenses
  - Minimize Exposure to Threat

Counter/Suppress Defenses

Required Damage Levels

Attack Axis

Re-Attack Plans

Alternate Target Plans

Targets of Opportunity

Target Vulnerability/Hardness

Target Area Weather

Cell/Command Operations

- Coordination
- Communications
- Weapon Frag Clearance
- Formation Spacing
- Defensive Requirements
- Offensive Abilities/Mutual Support
- Situation Awareness
- Timing
- Weather

Weapon Selection

- Type of Target
- Level of Destruction Required
- Platform/Weapon Accuracy
  - Aircraft Fire Control System Capabilities
  - Release Parameters
  - Drag Options
- Type of Munition, Yield
- Lethal Radius
- Fuzzing/Arming Requirements
  - Timing
  - Proximity - Burst Height
  - Impact Angle
  - Release Altitude
- Defenses
- Weather
- Cell Attack Tactics
- Aircraft Configuration
  - Weight

- Drag
- Aircraft Performance & Range Degradation
- Availability
- Expense
- Carriage Capability

Weapon Employment Envelope

- Delivery Mode
- Minimum Attack Perimeter
- Weather
- Release Parameters
  - Interval/Footprint
  - Release Timers
  - Dive Angle
  - Airspeed
  - Weapon Impact Angle
  - Release Altitude
    - Terrain, Obstruction Clearance
      - Altitude Loss During Pull-out
      - Minimum Ground Clearance
      - Altimeter Lag
      - Target Elevation
    - Threat Exposure
    - Own ship Frag Damage
    - Cell Frag Damage
    - Secondary Explosions
    - Seeker Limits
    - Type of Weapon
    - Drag Options
    - Fuzzing Requirements
      - Time
      - Altitude (Proximity)
    - Type of release
      - Single
      - Triple
      - Multiple/Ripple

Threat Reaction

- Air-Air Threats

Air-Ground Threats
Time Restraints
Refueling, Support Coordination
Alternate Targets
Abort Criteria, Procedures
Emergency Procedures
Downed Aircraft Procedures
Recovery Procedures

C2 Technical Orders

Air Force publications that give specific technical directions and information with respect to the inspection, operation, and maintenance of aircraft equipment and weapons systems. Includes performance capabilities and limitations of all aircraft systems.

C3 Doctrine/Rules of Engagement (ROE)

The rules, propositions, operational methods, tactics and teaching doctrines that have official sanction or authority to be used to guide and direct pilot actions during the Tactical Air-Ground Mission.

Engagement Tactics
Weapons Selection, Employment
Operational Procedures and Restrictions

C4 Aircraft Safety

Those items directly related to aircraft survivability and requiring immediate attention to avoid pilot injury or fatality. Conditions that require corrective actions that take immediate precedence over current actions and require the interruption and preemption of current tasks, due to the impending destruction of the aircraft due to threat activity, catastrophic systems failures, ground/obstruction clearance, collision avoidance, or pilot physiological condition/incapacity.

Items of concern include:

- Threat Status
- Terrain Clearance
- Obstacle Avoidance
- Pilot Reaction to Chemical Exposure
- Pilot Wounds
- Pilot G Tolerance/Capability - G Induced Loss of Consciousness (GLOC)
- Pilot Illness, Fatigue
- Aircraft Status- Structural Integrity,Energy State, Fuel State, Systems Status
- Collision Avoidance

A0 PERFORM TACTICAL AIR-GROUND MISSION

A1 CONTROL AIRCRAFT

Pilot performance of those actions that involve controlling aircraft flight parameters, navigation, communications, and aircraft systems monitoring and management.

A2 DEFEND AIRCRAFT

Pilot performance of those actions that involve the defense of the aircraft against ground based and airborne threats.

A3 OFFENSIVE ACTIONS

Pilot performance of those offensive actions that involve the use of aircraft munitions against ground based and airborne targets.

A4 MANAGE MISSION PHASES

Pilot evaluation of current mission status based on aircraft system performance, target status, fuel and stores, aircraft position, environmental status, mission/phase, and threats status to determine the current/subsequent course of action and transition between various mission phases.

A1 CONTROL AIRCRAFT

A11 FLY AIRCRAFT

Perform those actions that involve controlling aircraft flight parameters and executing flight procedures.

- Airspeed
- Altitude
- Attitude
- Heading/Course
- Angle of Attack
- Flight Path
- G Loads
- Evasive/Combat Maneuvering
- Ground Operations
  - Taxiing, Braking

A12 NAVIGATE

Perform evaluation of the current aircraft status, position, Mission Plans, Enroute Plans, and threat location and status. Pilot determination of navigation alternatives and operations and the execution of navigation procedures.

Environmental Effects
- Weather
- Visibility
- Wind
- Icing
- Terrain Features
- Terrain, Obstruction Clearance

Timing Constraints
Fuel State, Refueling Options
Aircraft Range
Target Location
Stores Limitations, Restrictions

A13 COMMUNICATE

Perform those actions that involve flight communications using verbal or coded requests, responses, acknowledgments and information to other inflight aircraft and ground facilities.

Communications with Cell, AWACS, ARTCC, Command Post etc.

Hand/Light/Formation Signals
Secure Voice Communication Systems
Voice Communication Systems
IFF
JTIDS, Data Links

A14 MANAGE AIRCRAFT SYSTEMS

Perform those actions that involve the control and configuration of aircraft systems through monitoring of current status, performance, and malfunctions.

Systems Malfunctions
Systems Performance Levels

Aircraft, Systems Configuration
Aircraft Damage
Stores Jettison

A11 FLY AIRCRAFT

A111 PERFORM EVASIVE/COMBAT MANEUVERS

Perform those actions that involve controlling aircraft flight path, direction, and energy state while employing combat maneuvers and tactics against threat site, threat aircraft and threat weapons.

Desired Flight Path changes
Changes to Aircraft Attitude, G Loads, Angle of Attack,
  Energy State
Collision Avoidance
Air Combat Maneuvers and Tactics
    Weapons, FCS Capabilities and Status
    Target, Threat Position and Closure Rates

A112 MAINTAIN DESIRED HEADING/COURSE

Perform those actions that involve controlling aircraft heading.

A113 MAINTAIN DESIRED ALTITUDE

Perform those actions that involve controlling aircraft altitude.

A114 MAINTAIN DESIRED AIRSPEED

Perform those actions that involve controlling aircraft airspeed.

A12 NAVIGATE

A121 IDENTIFY SPATIAL & TEMPORAL DIFFERENCES BETWEEN TARGET & OWNSHIP

Perform those actions that involve evaluation of target and ownship geometry and closure rates.

A122 DETERMINE PERFORMANCE OF AIRCRAFT

Perform those actions that involve the evaluation of ownship systems performance levels.

Systems Performance
Aircraft Configuration
Stores Limitations, Effects

A123 DETERMINE ENVIRONMENTAL INFLUENCES ON THE AIRCRAFT

Perform those actions that involve the evaluation of environmental effects on ownship systems performance.

Weather
    Heat, Humidity, Barometric Pressure, Wind, Icing
Visibility
Obstructions Clearance
Terrain Clearance

A124 MAKE NAVIGATIONAL DECISIONS

Evaluate aircraft navigation status and determine navigation actions.

Own ship Position, Heading, Altitude, Airspeed
Winds
Desired Course, Altitude, Airspeed
Threat Location, Status
Time
Fuel

A14 MANAGE AIRCRAFT SYSTEMS

A141 MONITOR AIRCRAFT SYSTEMS

Perform those actions that involve the monitoring of aircraft systems and determination of systems status, performance, and malfunction effects.

A142 CONFIGURE AIRCRAFT SYSTEMS

Perform those actions that involve the configuration of ownship systems based on systems performance levels, malfunctions work arounds, task requirements and goals, and mission phase.

A1421 CONFIGURE COMM/NAV SYSTEMS

Perform those actions that involve the configuration of communications and navigation systems for the current mission phase.

A1422 CONFIGURE DEFENSIVE SYSTEMS

Perform those actions that involve the configuration of Defensive systems for the current mission phase.

A1423 CONFIGURE OFFENSIVE SYSTEMS

Perform those actions that involve the configuration of Offensive systems for the current mission phase.

A1424 CONFIGURE MISCELLANEOUS SYSTEMS

Perform those actions that involve the configuration of configure Miscellaneous systems for the current mission phase.

Flight Control Systems (Autopilot, Trim, Stability)
Propulsion
Lighting - Internal, External
Environmental Control Systems
Cabin Pressure, Heating, Cooling, Oxygen
Landing Gear
Flaps
Speed Brakes
Spoilers

A2 DEFEND AIRCRAFT

A21 MONITOR THREATS

Perform those actions that involve the defense of the aircraft by the monitoring of threats and the determination of threat mode, status, and priority.

Threat Mode/Status
Threat Priority
Threat Location
Closure Rates
Occulting Status
Missile Launch
Gun Firing
Air Combat Maneuvering
Threat Countermeasure Decisions
Threat Detection, Identification
- Visual
  - Visual Sighting, Reflections, Smoke, Tracers, Missile Engine Burn
- Sensors
  - Radar, IR, EO Sensors
- RWS/RHAW/TEWS
  - Threat Identification, Threat Mode, Aural Warning Tones, Prioritization,Symbology

Monitor Threat Reactions

A22 COUNTER SAM/AAA/AI THREAT

Perform those actions that involve the defense of the aircraft by implementation of SAM/AAA/AI defensive systems, procedures and actions.

Expendable Countermeasures (EXCM)
Electronic Countermeasures (ECM)
Evasive Maneuvers

A23 DETERMINE THREAT SUPPRESSION OPTIONS

Perform those actions that involve the defense of the aircraft by determination of SAM/AAA/AI threat suppression or destruction capability and options.

Threat Location
Target Location
Occulting
Threat Mode, Status
Fuel State
Time
Mission Plan
Stores
Course/Route Constraints, Options

A24 COUNTER CHEMICAL WEAPON THREAT

Perform those actions that involve implementation of chemical defensive procedures.

<u>A22 COUNTER SAM/AAA/AI THREAT</u>

A221 COUNTER SAM/AAA/AI SYSTEMS

Pilot action in the defense of the aircraft by employment of defensive countermeasures systems and procedures to counter the threat.

A222 EXECUTE SAM/AAA/AI EVASIVE MANEUVERS

Pilot actions in the defense of the aircraft by employment of defensive evasive maneuvers to counter the threat.

Own ship Position, Velocity
Threat Range, Bearing, Closure Rate
Target Location
Occulting
Threat Mode, Status
Fuel State
Stores
Course/Route Constraints, Options
Interceptor/Missile Position, Angle, Closure Rate
Tactics

A223 COMBINED SAM/AAA/AI EFFECTS

The combined result of pilot defensive actions against SAM/AAA/AI threats.

EXCM, ECM, Evasive Maneuvers

<u>A221 COUNTER SAM/AAA/AI SYSTEMS</u>

A2211 DEPLOY EXPENDABLE COUNTERMEASURES

Pilot actions to dispense onboard Expendable Countermeasures

Flares
Chaff

Jammers

A2212 ACTIVATE ELECTRONIC COUNTERMEASURES

Pilot actions to activate onboard Electronic Countermeasures

Barrage/Noise Jamming
Sweep Jamming
Deception Jamming
Electronic IR Jamming
Spot Jamming

A2211 DEPLOY EXPENDABLE COUNTERMEASURES

A22111 ACTIVATE CHAFF PROGRAM

Pilot actions to activate the Chaff dispensing system.

A22112 ACTIVATE FLARE PROGRAM

Pilot actions to activate the Flare dispensing system.

A22113 ACTIVATE EXPENDABLE JAMMERS PROGRAM

Pilot actions to activate the Expendable Jammers dispensing system.

A2212 ACTIVATE ELECTRONIC COUNTERMEASURES

A22121 ACTIVATE DECEPTION JAMMING

Pilot actions to activate Deception Jamming Electronic Countermeasures.

A22122 ACTIVATE BARRAGE/NOISE JAMMING

Pilot actions to activate Barrage/Noise Jamming Electronic Countermeasures.

A22123 ACTIVATE SPOT JAMMING

Pilot actions to activate Spot Jamming Electronic Countermeasures.

A22124 ACTIVATE SWEEP JAMMING

Pilot actions to activate Sweep Jamming Electronic Countermeasures.

A22125 ACTIVATE INFRARED JAMMING

Pilot actions to activate Infrared Jamming Electronic Counter measures.

A24 COUNTER CHEMICAL WEAPON THREAT

A241 DON CW GEAR

Pilot actions to counter chemical threats by donning, activating, and checking available CW equipment (mask, gloves, etc.).

A242 ADMINISTER PROPHYLACTIC

Pilot actions to counter chemical threats by administering a pretreatment drug.

A243 ADMINISTER ANTIDOTE

Pilot actions to counter chemical threats by administering a antidote treatment drug.

A244 EXECUTE CW THREAT EVASION

Pilot actions to counter chemical threats by evasive actions.

A245 COMBINED CW COUNTERMEASURES EFFECTS

The combined effects of pilot actions to counter chemical threats.

A246 MONITOR CW THREAT SITUATION

Pilot actions to monitor chemical threats and determine subsequent actions.

A3 PERFORM OFFENSIVE ACTIONS

A31 PERFORM OFFENSIVE AIR-AIR

Perform those actions that involve offensive actions against airborne threats.

A32 PERFORM OFFENSIVE AIR-GROUND

Perform those actions that involve offensive actions against ground targets.

A31 PERFORM OFFENSIVE AIR-AIR

A311 CONFIGURE AIRCRAFT AIR-AIR

Perform those actions that involve the activation and configuration tasks required for an offensive air-air engagement.

A312 ATTACK AIR-AIR TARGET

Perform those actions that involve air combat maneuvering, target acquisition, and weapons delivery against an air-air target.

A313 DISENGAGE AIR-AIR TARGET

Perform those actions that involve disengagement from air combat against an air-air target.

<u>A311 CONFIGURE AIRCRAFT AIR-AIR</u>

A3111 CONFIGURE FIRE CONTROL & WEAPON SYSTEMS

Perform those actions that involve the configuration of the Fire Control System and Weapon Systems

- BIT Checks
- Select Air-Air Master Mode
- Weapons Selection
  - Missile Selection, Station Selection
    - Arming
    - Tuning - cooling, battery power, guidance, seekers
  - Guns Select/Arming

A3112 CONFIGURE RADAR SYSTEM

Perform those actions that involve the configuration of the Radar System.

Channel
Radar Mode
Elevation Strobe
Brightness
Sector Coverage
Polarity
Contrast
Symbology

A3113 CONFIGURE COUNTERMEASURE SYSTEMS

Perform those actions that involve the configuration of the Countermeasures Systems.

ECM Tuning, Programs
Flare Program
  Burst Count, Interval
Chaff Program
  Salvo Count, Interval
  Burst Count, Interval
Radar Warning Equipment
  Display Controls
  Aural Tones Volume

A3114 CONFIGURE MISCELLANEOUS SYSTEMS

Perform those actions that involve the configuration of miscellaneous aircraft systems.

Configure Lighting
  Internal Lighting
  External Lighting
Configure Fuel

Jettison Tanks
Transfer Fuel
Check Fuel Status
Configure Electro-Optics Search/Targeting System
Configure HUD

A312 ATTACK AIR-AIR TARGET

A3121 ACQUIRE AIR-AIR TARGET

Perform those actions that involve the acquisition and designation of the target for weapons release.

Defensive Maneuvering
Offensive Maneuvering
Threat Status
Threat Location
Own ship Status
Sensor Status, Capabilities

A3222 RELEASE WEAPONS

Perform those actions that involve the delivery of weapons against an airborne target.

A3122 EXECUTE AIR COMBAT MANEUVERS & TACTICS

Perform those actions that involve aircraft maneuvering against an airborne target. Defensive Maneuvering

Threat Actions
Attack Geometry
Own ship Status
Own ship/Threat Energy States
Rules of Engagement
Air-Air Combat Tactics

Weapon Delivery Parameters
FCS and Weapon System Capabilities, Limitations

A3123 RELEASE AIR-AIR WEAPONS

Perform those actions that involve the delivery of weapons against the airborne target.

A32 PERFORM OFFENSIVE AIR-GROUND

A321 INGRESS TO IP

Perform those actions that involve a low level ingress to the target IP. Completion of all pre-attack phase tasks and aircraft configuration in order to minimize all required actions during the attack phase.

Emphasis: Limit Attack Concerns Prior to IP
- Lessen/Relieve Workload During Ingress to IP

Check Aircraft Systems Status
- Weapons, FCS Status
- Fuel Status
- Perform BIT Checks

Abort Attack Decisions
- Systems Malfunctions
- Timing Problems
- Fuel
- Unanticipated Threats
- Threat Actions
- Support Problems

Radar/IR Check for Bandits
Cell/AWACS coordination

A322 ATTACK TARGET

Perform those actions that involve the attack target segment of the mission - including target acquisition and weapon release.

- Hack Clock
- Fly an Unpredictable Flight Path
- Approach Terrain
- Target Elevation
- Threat Locations
- Low Altitude Ingress
- Weather Maneuvering
- Obstruction/Terrain Maneuvering
- Time-Over-Target Monitoring for attack airspeed control
- Minimum Altitude, Maximum Speed
  - Lowers Accuracy
  - Increases Survivability
  - Lowers Detection,
  - Decreases Acquisition Time
  - Critical Weapons Factors
    - Fuzzing Time
    - Release Altitude
    - Frag Damage
    - Impact Angles
    - Seeker Limits
    - Stores Airspeed Limits
    - Stores G Limits
    - Weapon/Seeker Cooling Requirements
    - Weapon Battery Limits
    - Weapon Tuning
    - Fuel Usage vs. Speed

  - CCIP Attack
    - Pop-up Not as Essential for Weapons Delivery Since Only a Visual Acquisition Required

  - CCRP Attack

Computer Driven, Requires Target Designation on HUD, Radar, INS

- Acquisition Maneuvers
  - Bombing Mode
    - Loft
    - Dive Toss
    - Level Bombing
  - Pop-Up
  - Pull-Down
  - Off-Axis (Angle-Off) Maneuver
    - Faster Acquisition
    - Unpredictable Flight Path
    - More Maneuvering Required Less Tracking Time Possible
  - On-axis Maneuver
- Acquisition Parameters
  - Altitude
  - Line of Sight to Target
  - Environmental Factors
    - Ambient Light
    - Smoke
    - Haze/Fog
    - Blowing Snow/Sand
    - Rain
    - Sun/Moon Angle
    - Visibility
  - Environmental Acquisition Problems
    - Increases Exposure Time
    - Decreases Target Acquisition Time
    - Formation Spacing
    - Shortens Release Range

- Visual Limitations/Restrictions
    - Range to Target
    - Altitude
    - Airspeed
    - Aspect - Azimuth, Elevation
- Winds
    - Decreased Accuracy
    - Blowing Obscurations
- Ground Beacons, Smoke Markers, FAC Directions
- Expected Range, Bearing to Target vs. Actual
- Target Features
    - Surrounding Terrain
        - Features
        - Type
        - Colors
    - Size
    - Features
    - Spacing, Orientation
    - Color
    - Reflections
    - Contrast Ratio
- Target Electronic Emissions
- Mobile Targets - Visual Designation Desired
- Intelligence, Target Information
- Target Designator Box Cues
- Closure Rates, Time for Acquisition

Target Designation
- Visual - Eyes, HUD
- EO, TV, FLIR
- Radar
- INS
- Dead Reckoning

Damage Assessment - Pre-Attack
Evaluate target damage level

A323 DISENGAGE TARGET

Perform those actions that involve the evaluation of target and attack status for determination of attack pass abort, re-attack or termination options.

A324 EGRESS TARGET AREA

Perform those actions that involve the Post attack Evaluation of target and attack status for determination of re-attack or termination and RTB options.

<u>**A321 INGRESS TO IP**</u>

A3211 FLY TO IP

Perform those functions performed during the ingress to the IP. Tasks include navigation, cell communications and coordination, attaining proper timing, threat monitoring.

A3212 CONFIGURE AIRCRAFT

Perform those actions that involve Pilot conducting aircraft operations in terms of configuring the various onboard aircraft systems.

A3213 PERFORM NAV UPDATE

Perform those actions that are necessary to identify the IP and perform an INS/Navigation Update.

A3211 FLY TO IP

A32111 PERFORM LOW LEVEL PENETRATION

Perform those actions that involve the performance of a low level target penetration.

A32112 COORDINATE WITH CELL/AWACS

Perform those actions that involve the coordination of the ownship with the cell/AWACS/Command members.

A32113 SOLVE TIMING PROBLEMS

Perform those actions that involve meeting the time requirements for navigation, weapon delivery, and mission coordination.

A32114 CHECK TARGET AREA FOR BANDITS

Perform those actions that involve searching the target area and approach for enemy aircraft.

A3212 CONFIGURE AIRCRAFT

A32121 CONFIGURE FIRE CONTROL & WEAPON SYSTEMS

Perform those actions that involve the configuration of the Fire

Control System and Weapon Systems

Perform BIT Checks
Select Air-Ground Master Mode

Weapons Selection
  Select Weapon Delivery Mode
  Weapon Selection, Station Selection
    Fuzzing
      Nose/Tail
      Type Fuzzing - Proximity, Time, Impact
    Arming
    Interval
    Release Parameters
    Pull-up Timers
    Release Timers

HUD Reticle Depression

Guns Selection, Firing Rate

Weapons Arming/Tuning
  Cooling
  Battery Power
  Guidance
  Seekers

A32122 CONFIGURE RADAR SYSTEM

Perform those actions that involve the configuration of the Radar System.

Channel
Radar Mode
Elevation Strobe
Brightness
Sector Coverage

Contrast
Symbology

A32123 CONFIGURE COMMUNICATION SYSTEM

Perform those actions that involve the configuration of the Communication System.

Secure Voice
Silent Communications
IFF
JTIDS

A32124 CONFIGURE NAVIGATION SYSTEM

Perform those actions that involve the configuration of the Navigation System.

Tune Radios
Select Navigation Mode
Waypoint Selection

A32125 CONFIGURE COUNTERMEASURE SYSTEMS

Perform those actions that involve the configuration of the Countermeasures Systems.

ECM Tuning, Programs

Flare Program
  Burst Count, Interval

Chaff Program
  Salvo Count, Interval
  Burst Count, Interval

Radar Warning Equipment
Display Controls
Aural Tones Volume

A32126 CONFIGURE MISCELLANEOUS SYSTEMS

Perform those actions that involve the configuration of miscellaneous aircraft systems.

Configure Lighting
Internal Lighting
External Lighting

Configure Fuel
Jettison Tanks
Transfer Fuel
Check Fuel Status

Configure Electro-Optics Search/Targeting Systems

Configure HUD
Display Symbology
Brightness
Camera

<u>**A32121 CONFIGURE FIRE CONTROL & WEAPON SYSTEMS**</u>

A321211 SELECT A/G MASTER MODE

Pilot actions to select the A/G Master Mode.

A321212 SELECT WEAPON DELIVERY MODE

Pilot actions to select the desired Weapon Delivery Mode.

Selected Bombing Mode

A321213 SELECT WEAPON PARAMETERS

Pilot actions to select weapon parameters.

Weapon Type Selection
Station Selection
Fuzzing Parameters

A321214 SELECT WEAPON RELEASE PARAMETERS

Pilot actions to select the weapon release parameters.

Interval
Timers
Adjust HUD Reticule Depression

A321215 ARM WEAPONS

Pilot actions to tune, arm selected weapons.

A/G Weapons Tuned, Armed
Gun Arming, Firing Rate

A321216 PERFORM FCS & WEAPONS BIT CHECKS

Pilot actions to execute Built-In-Test diagnostics for the Fire Control System and Weapons System.

A32122 CONFIGURE RADAR SYSTEM

A321221 PERFORM RADAR BIT CHECKS

Pilot actions to execute Built-In-Test diagnostics for the Radar System.

A321222 SELECT RADAR CONTROL PANEL FUNCTIONS

Pilot selection of Radar Control Panel Functions.

A321223 ADJUST RADAR DISPLAY

Pilot adjustment of Radar Display Controls.

A321224 ADJUST ANTENNA ELEVATION

Pilot adjustment of Radar Antenna Elevation Angle Controls.

Radar beam grazing angle
Radar energy returns

A321222 SELECT RADAR CONTROL PANEL FUNCTIONS

A3212221 SELECT RADAR MODE

Pilot selection of Radar Mode parameters.

Ground Map Modes
A/A Modes
NAV Modes

A3212222 SELECT SEARCH PARAMETERS

Pilot selection of Radar Search parameters.

Range
Azimuth Scan Width
Number of Elevation Bars

A3212223 SELECT FREQUENCY PARAMETERS

Pilot selection of Radar Frequency parameters.

RF Channel
PRF

A3212224 SELECT MISCELLANEOUS PARAMETERS

Pilot selection of Miscellaneous Radar Control functions.

Target History
Marker Intensity
Map Freeze

A321223 ADJUST RADAR DISPLAY

A3212231 ADJUST SYMBOLOGY INTENSITY

Pilot adjustment of Radar Display Symbology Controls.

A3212232 ADJUST VIDEO GAIN

Pilot adjustment of Radar Display Video Gain Controls.

A3212233 ADJUST VIDEO INTENSITY

Pilot adjustment of Radar Display Video Intensity Controls.

A3212234 ADJUST VIDEO CONTRAST

Pilot adjustment of Radar Display Video Contrast Controls.

A32123 CONFIGURE COMMUNICATION SYSTEM

A321231 SELECT COMMUNICATION MODE

Pilot selection of Communication Mode parameters.

A321232 TUNE COMMUNICATION RADIOS

Pilot selection of Communication Radio frequency/channel.

Selected Channels/Frequencies

A321233 SELECT SECURE VOICE MODES

Pilot selection of Secure Voice Communication Modes.

A321234 SELECT IFF MODES

Pilot selection of IFF Mode & Interrogation parameters.

IFF Mode
IFF Transponder Codes

A32124 CONFIGURE NAVIGATION SYSTEM

A321241 PERFORM INS BIT CHECKS

Pilot actions to execute Built-In-Test diagnostics for INS System.

A321242 SELECT NAVIGATION MODES

Pilot selection of Navigation Mode parameters.

A321243 VERIFY INS COORDINATES

Pilot actions to check actual coordinates vs. INS coordinates.

Waypoint Location Coordinate Entries
Own ship Actual Position
INS Computed Own ship Position

A321244 TUNE NAVIGATION RADIOS

Pilot selection of Navigation radio frequencies/channels.

A32125 CONFIGURE COUNTERMEASURES SYSTEMS

A321251 CONFIGURE ELECTRONIC COUNTERMEASURES SYSTEM

Perform those actions that involve the configuration of the Electronic Countermeasures System.

A321252 CONFIGURE EXCM SYSTEM

Perform those actions that involve the configuration of the Expendable Countermeasures System.

A321252 CONFIGURE EXCM SYSTEM

A3212521 SELECT FLARE PARAMETERS

Pilot selection of Flare Program parameters.

Burst Count, Interval

A3212522 SELECT CHAFF PARAMETERS

Pilot selection of Chaff Program parameters.

Burst Count, Interval
Salvo Count, Interval

A3212523 SELECT EXCM PROGRAM

Pilot selection of Expendable Countermeasures Program.

A3212524 ARM EXCM SYSTEM

Pilot Arming of the Expendable Countermeasures System.

A32126 CONFIGURE MISC. SYSTEMS

A321261 CONFIGURE FUEL SYSTEM

Perform those actions that involve the configuration of the Fuel System.

Jettison Tanks
Transfer Fuel
Check Fuel Status

A321262 ASSIGN TARGET DESIGNATOR CONTROL (TDC)

Pilot assignment of the TDC for designation from the desired display.

HUD, Radar, HSI

A321263 ADJUST LIGHTING

Pilot adjustment of aircraft lighting controls.

Interior, Exterior

A321264 ADJUST ELECTRONIC DISPLAYS

Pilot adjustment of various electronic display controls.

Weapons Video
Multi-function Displays
Electro-Optical Search/Acquisition Systems

A321265 ADJUST HUD CONTROLS

Pilot adjustment of the Heads Up Display controls.

Symbology
Brightness
Camera Controls

A322 ATTACK TARGET

A3221 ACQUIRE TARGET

Perform those actions that involve the visual, radar, or electro-optical acquisition and designation of the target for weapons release.

Start Countermeasures
- Evasive Maneuvers/Jinking
- Preventative Countermeasures (EXCM, ECM)

Threat Status
- Ignore
- Counter Measures
- Evade Defenses
- Abort Attack Pass
- Abort Attack
- Suppress/Destroy Threat

Considerations
- Lower, Slower - More accurate, riskier

A3222 RELEASE WEAPONS

Perform those actions that involve the delivery of weapons against the ground target.

A3223 ASSESS TARGET DAMAGE

Determine target damage levels and degree of success with respect to acceptable levels of damage.

A3221 ACQUIRE TARGET

A32211 EXECUTE ACQUISITION MANEUVER

Perform those actions that involve maneuvering the aircraft so that target acquisition can be accomplished and maintained.

- Threat Exposure
  - Threat Location
  - Threat Mode, Status
  - Occulting, Line of Sight

- Weapon Release Parameters
  - Weapon Delivery Mode
  - Weapon Fuzzing
  - Ground/Obstacle Clearance

- Pop-Up Angle
- Pop-Up G's
- Pop-Up Altitude
- Pull-Down G's

A32212 PERFORM TARGET ACQUISITION

Perform those actions that involve visual or sensor target acquisition.

A32213 DESIGNATE TARGET

Perform those actions that involve weapon system or sensor target designation for weapons delivery solutions.

A32212 PERFORM TARGET ACQUISITION

A322121 PERFORM VISUAL ACQUISITION

Perform those actions that involve visual acquisition of the target in conjunction with HUD and electro-optic systems.

A322122 PERFORM RADAR ACQUISITION

Perform those actions that involve radar acquisition of the target.

A322123 PERFORM INS ACQUISITION

Perform those actions that involve INS acquisition of the target.

A322124 PERFORM DEAD RECKONING ACQUISITION

Perform those actions that involve dead reckoning navigation to the target.

- Timing
- Airspeed
- Position
- Distance
- Heading
- Timing
  - Coordinated Attacks
  - Frag Avoidance
  - Secondary Explosions

A32222 TRACK TARGET

Perform those actions that involve maintaining a flight path that will allow accurate weapon delivery. In addition, assess current target damage for attack abort decisions.

Attack Run Target Damage Assessment
Continue Attack
Abort Attack (Acceptable Damage Levels)
Track Target
Release Airspeed
Dive Angle
G's
Release Altitude
Winds
Azimuth Tracking/Ground Path

Fly to Release Point, Roll-in Point

A32223 FLY TO RELEASE POINT

Perform those actions that involve maintaining a flight path that will allow accurate weapon delivery at the necessary weapon release point.

Track Target to Release Point

A32224 RELEASE WEAPONS

Perform those actions that involve munitions delivery.

Pickle
Trigger
Weapon Delivery

Pop-up Well Before Minimum Attack Perimeter (MAP)
MAP Based on Roll-out, Target Tracking, Pickle

TD Box Location
CCIP Display and Target Location
CCRP Steering Cues

Velocity Vector, Attitude, Altitude, Airspeed,
Time to Go, G's, Release Cue, Pull-up Cue

AOA, HSI, ADI, INS, HUD/Optical Sight, Radar, Audio
Tones, Release/Pull-up Cues, Pull-up Timers

Drag Options
Dive Angle
Release Speed

Target Tracking - MAP - Release Point Coordination

Timing/Spacing
- Frag Damage
- Cell Coordination

A323 DISENGAGE TARGET

A3231 EXECUTE ESCAPE MANEUVER

Perform those actions that involve aircraft maneuvers to clear the target area and avoid threats.

- Escape Maneuvers
  - Terrain Avoidance, Max Airspeed
    - Visibility
    - Ceilings
    - Fuel Usage
  - High G Pull-up
  - High G Level Turn
  - High G Pull-up, Turn
  - Fragmentation, Secondary Explosions Avoidance
  - Cell Coordination

A3232 RE-JOIN CELL

Perform those actions that involve reforming with the attack package/cell members.

A3233 EVALUATE AIRCRAFT STATUS

Perform those actions that involve determination of post-attack aircraft systems, aircraft status, and pilot physiological condition and capabilities.

- BIT Checks
- Visual Inspection
- Safe Weapons
- Safe Countermeasures Systems

A3234 DETERMINE RE-ATTACK PLANS

Perform those actions that involve determination of re-attack options based on attack status, aircraft status, and target status.

- Target Damage Assessment - Post Attack
  - Acceptable Levels of Damage
  - Unsuccessful Release

- Execute Countermeasures
  - Preventative Actions

- Follow-Up Actions
  - Abort Mission
  - Reattack Target
  - Secondary/Alternate Target

A324 EGRESS TARGET AREA

A3241 DETERMINE MISSION OPTIONS

Perform those actions that involve determination of re-attack options, abort decisions, alternate target selection and attack and mission disengagement.

- Determine Actions/Options
  - Available Time
  - Available Stores
  - Aircraft Systems Status
  - Battle Damage
  - Pilot/Crew Condition
    - Fatigue, Wounds, Chemical Exposure
  - Downed Aircraft
  - Alternate Target Decisions

A3242 RE-FUEL AIRCRAFT

Perform those actions that involve inflight aircraft refueling.

- Alternate Target Decisions
- Mission Plan
- Fuel State

A3243 PROCEED TO ALTERNATE/SECONDARY TARGET

Perform those actions that involve navigation to alternate or secondary targets.

- Available Fuel, Refueling Options
- Alternate Along Egress Route

A3244 RETURN TO BASE

Perform those actions that involve egress to recovery base.

A3245 CONFIGURE AIRCRAFT FOR EGRESS

Perform those actions that involve the configuration of the aircraft for egress to the recovery base.

- Configure Countermeasures Systems
- Configure Comm/Nav Systems
- Configure Radar Systems
- Configure Misc. Systems
- Configure FCS/Weapon Systems
  - Air-Air Weapon Selection, Arming
  - Jettison Stores

A3246 COORDINATE WITH CELL/AWACS

Perform those actions that involve Cell/AWACS coordination and communication.

A4 MANAGE MISSION PHASE

A41 EXECUTE MISSION PHASES

Perform those actions that involve completion of the current mission phase objectives and making enroute plans and revisions.

A42 ASSESS MISSION PHASES

Perform those decisions that involve the completion, transition, and continuation of the current mission phase based on Mission Status and conditions.

A41 EXECUTE MISSION PHASES

A411 EXECUTE TAKEOFF

Perform those actions that involve takeoff phase tasks.

A412 EXECUTE OUTBOUND/INBOUND CRUISE

Perform those actions that involve cruise phase tasks.

A413 EXECUTE INGRESS/EGRESS

Perform those actions that involve ingress/egress phase tasks.

A414 EXECUTE TARGET ENGAGEMENT

Perform those actions that involve target attack phase tasks.

A415 EXECUTE RECOVERY AND LANDING

Perform those actions that involve aircraft recovery and landing tasks.

A42 ASSESS MISSION PHASES

A421 ASSESS SYSTEM

Determine system capabilities and status based on aircraft performance, battle damage and malfunctions.

A422 ASSESS ENVIRONMENT

Determine environmental effects on aircraft capabilities and mission performance.

A423 ASSESS PHASE OBJECTIVE

Determine the status of current phase objectives, mission status, capabilities, and current actions.

A424 DEFINE COURSE OF ACTION

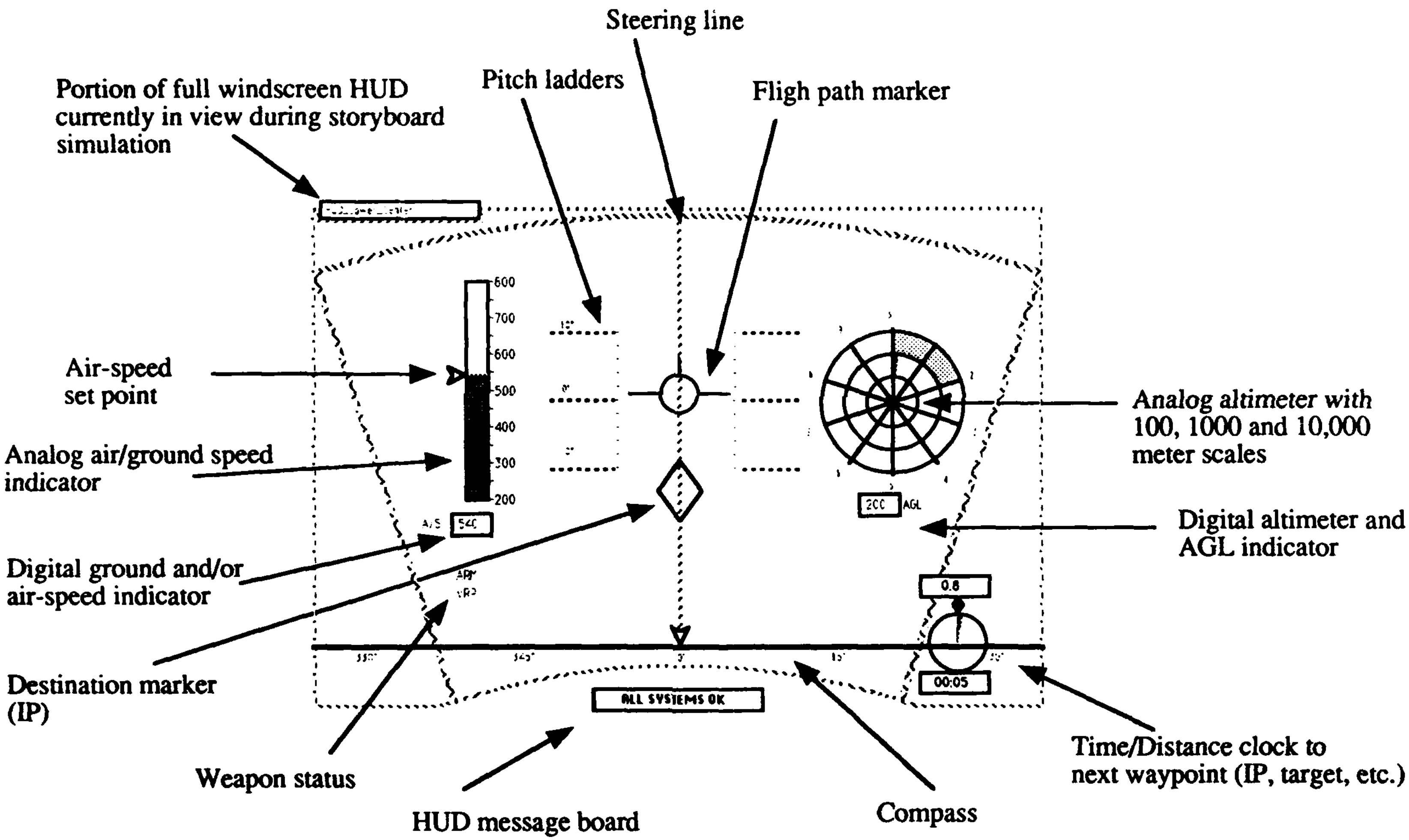
Determine subsequent plans and actions necessary to achieve mission/phase objectives based on current status, conditions and possible alternatives.

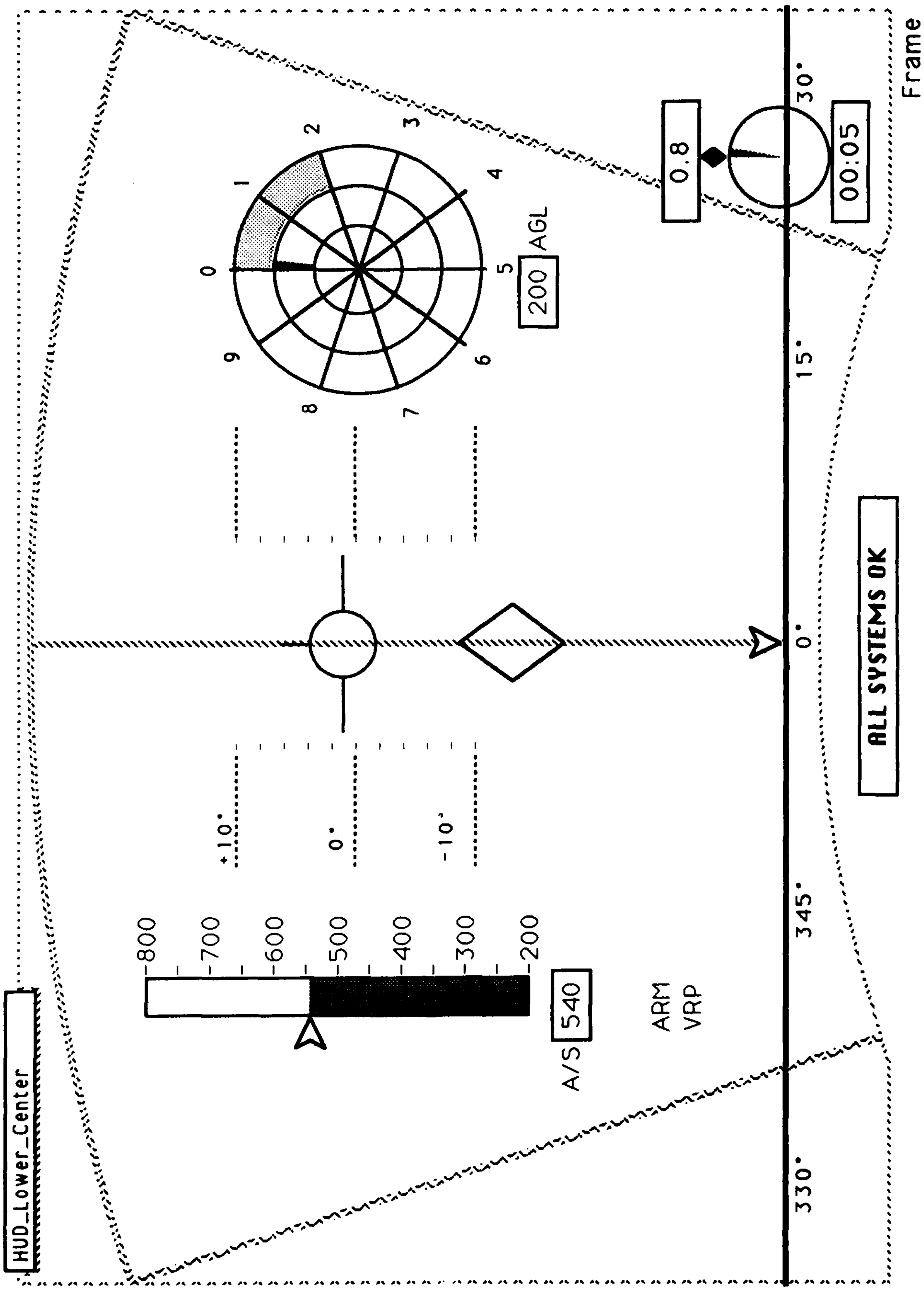
- Mission Abort/Continuance Decisions
  - Malfunctions Effects
  - Battle Damage
  - Pilot Physiological Condition
  - Ejection Decisions
  - Downed Aircraft
  - Fuel State
  - Traffic
  - Weather, Environmental Effects
  - Threat Mode, Status
  - Malfunction Effects
  - Systems Status
  - Available Stores
  - Ownship Position
  - Mission Plan
    - Mission Goals
    - Abort Criteria
  - Doctrine/Rules of Engagement
  - Attack Package/Cell Status
  - Target Location, Status
  - Attack Status
  - Time

APPENDIX D

STORYBOARD PROTOTYPE

Storyboard Glossary of Design Object

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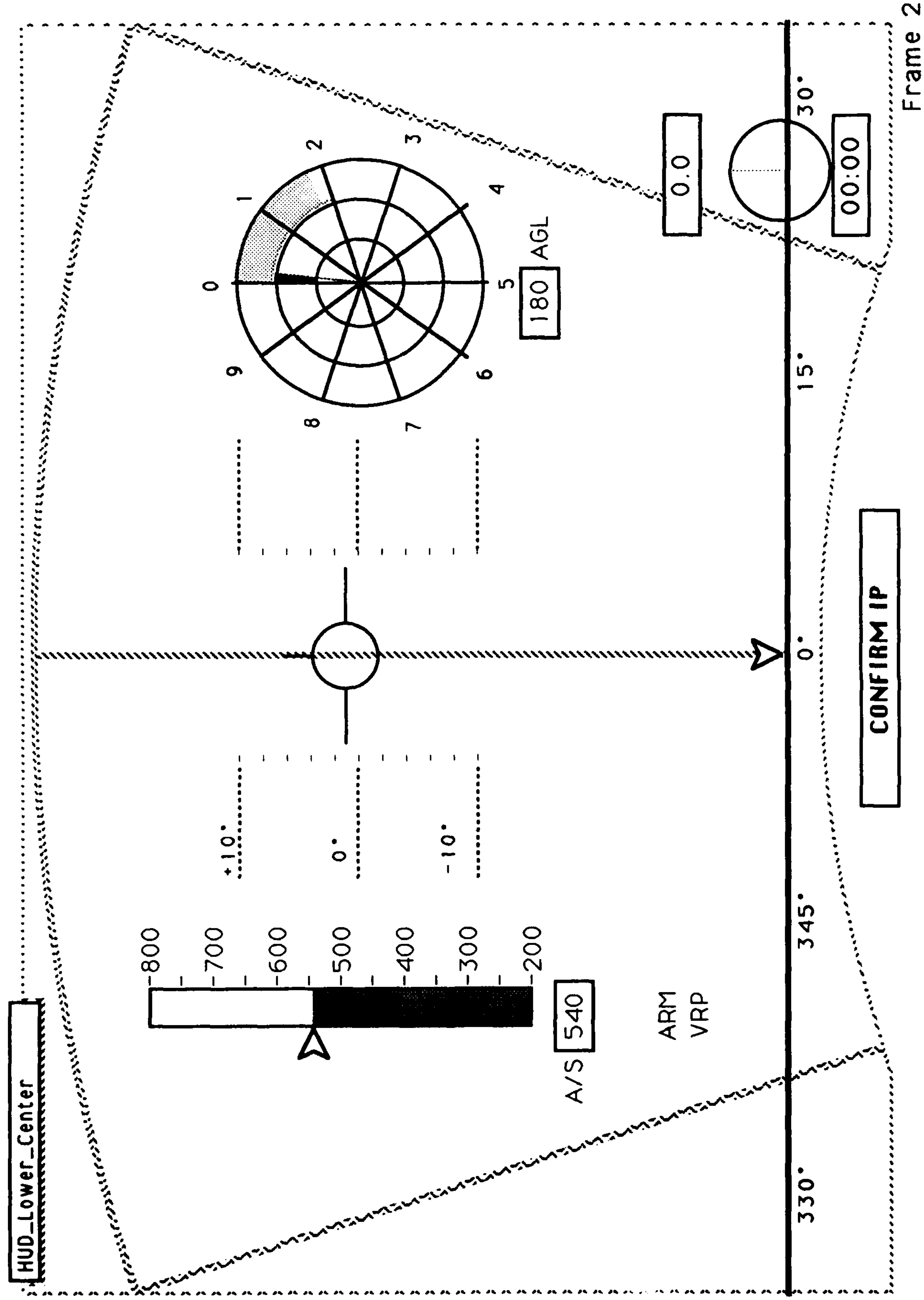
Frame 1
800
700
600
500
400
300
200
A/S 540
ARM
VRP
+10°
0°
-10°
0
1
2
3
4
5
6
7
8
9
200 AGL
0.8
00:05
ALL SYSTEMS OK
330°
345°
0°
15°
30°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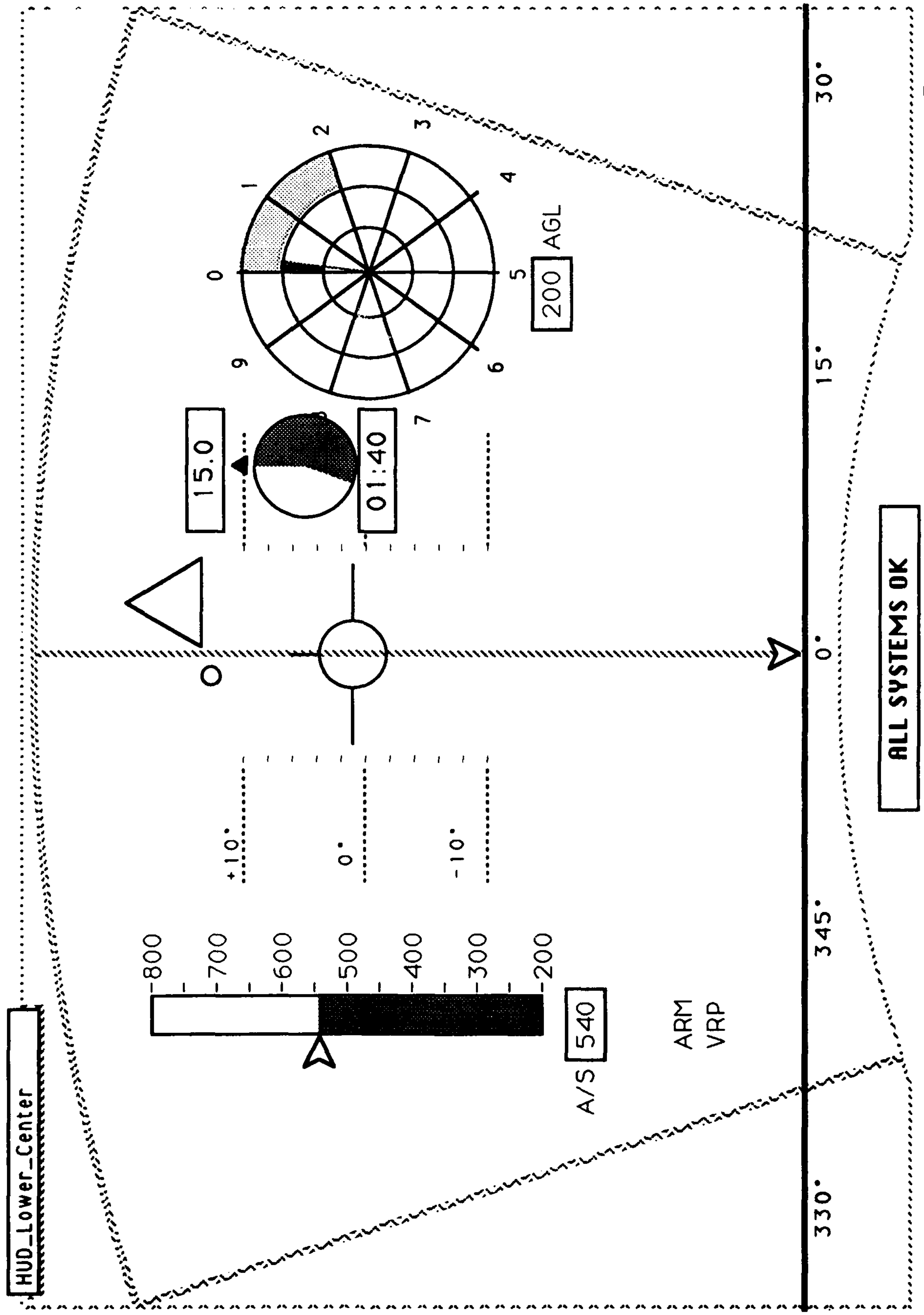
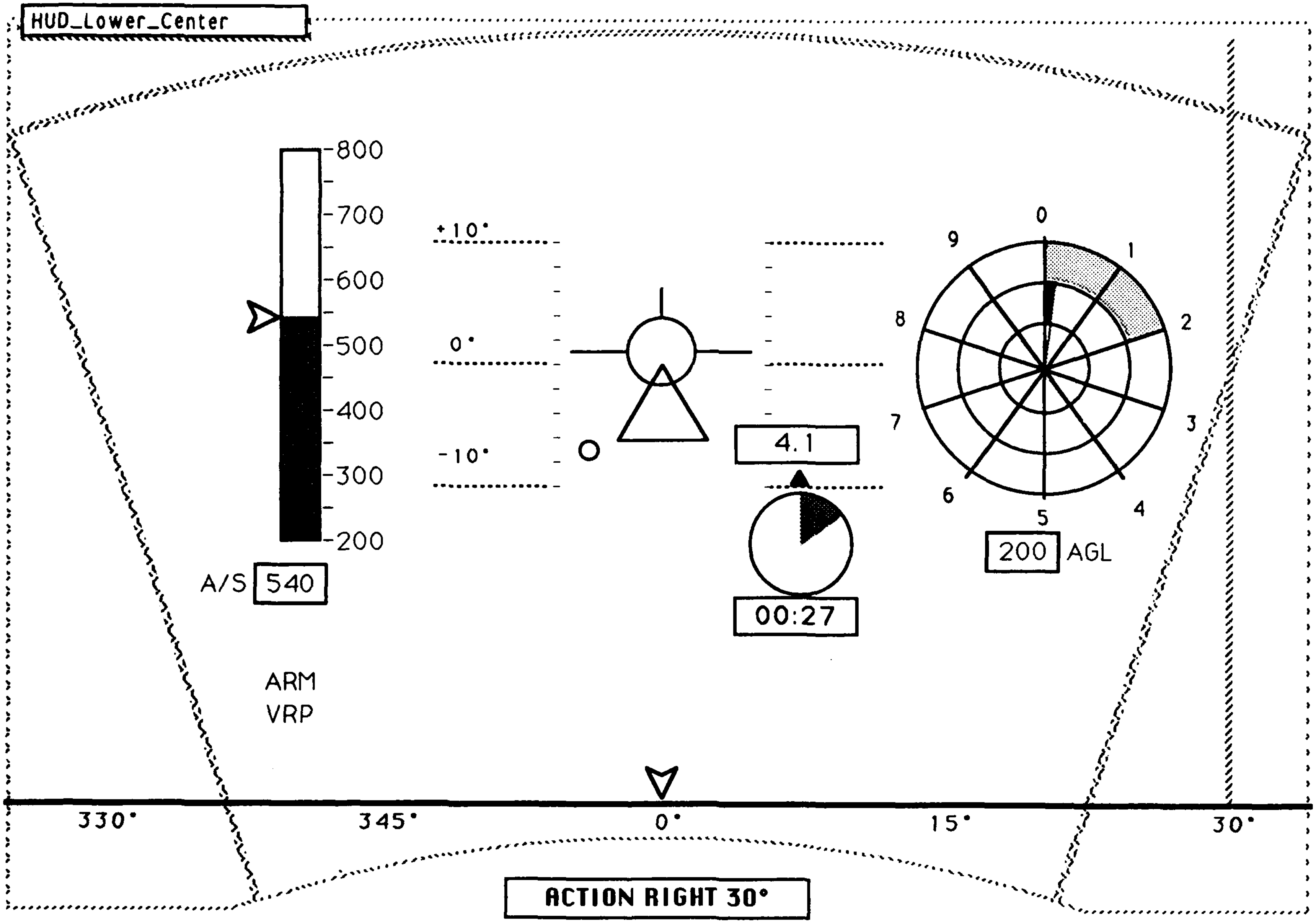
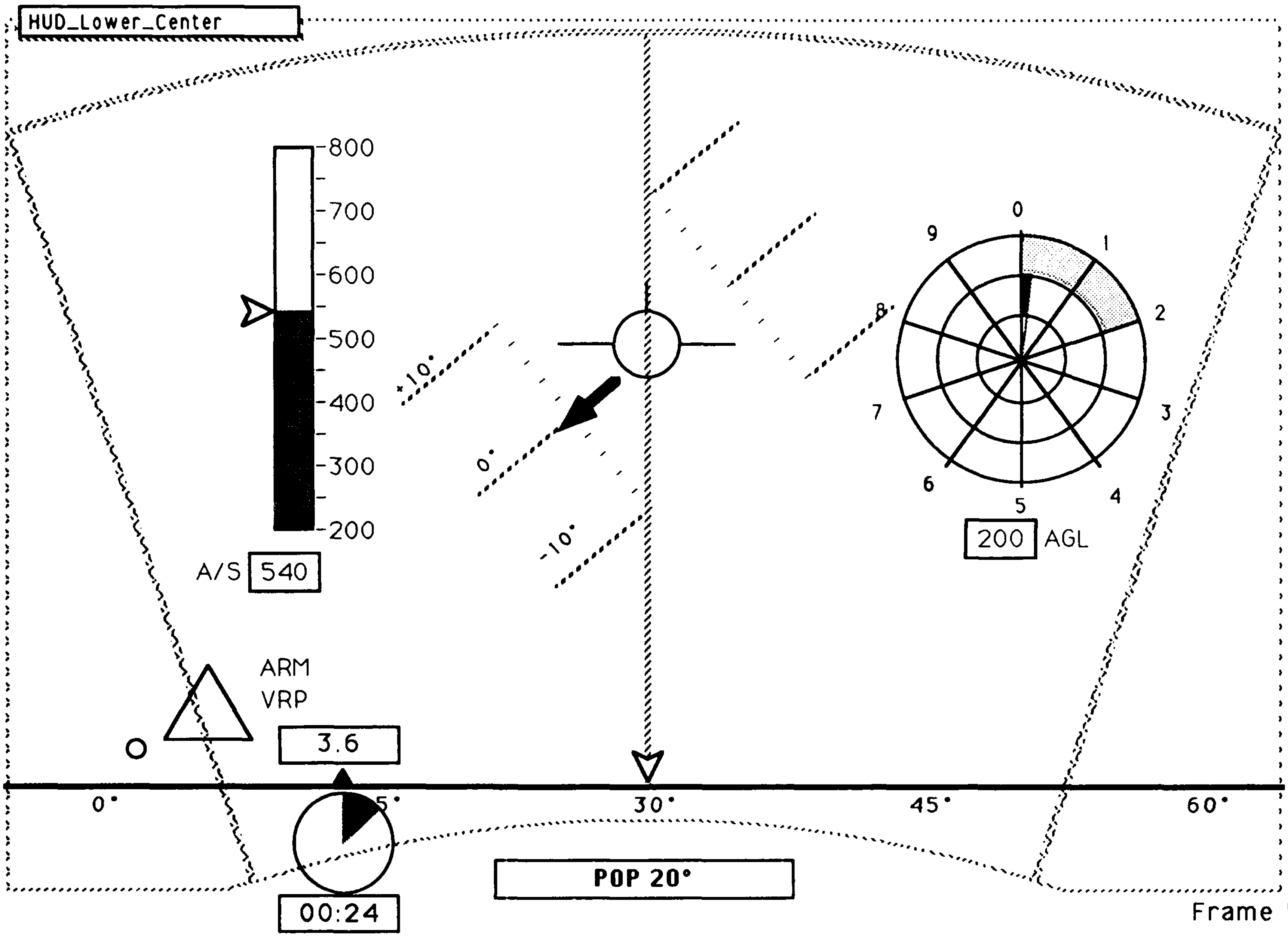
Frame 2
800
700
600
500
400
300
200
A/S 540
ARM
VRP
+10°
0°
-10°
0
1
2
3
4
5
6
7
8
9
180 AGL
0.0
00:00
330°
345°
0°
15°
30°
CONFIRM IP

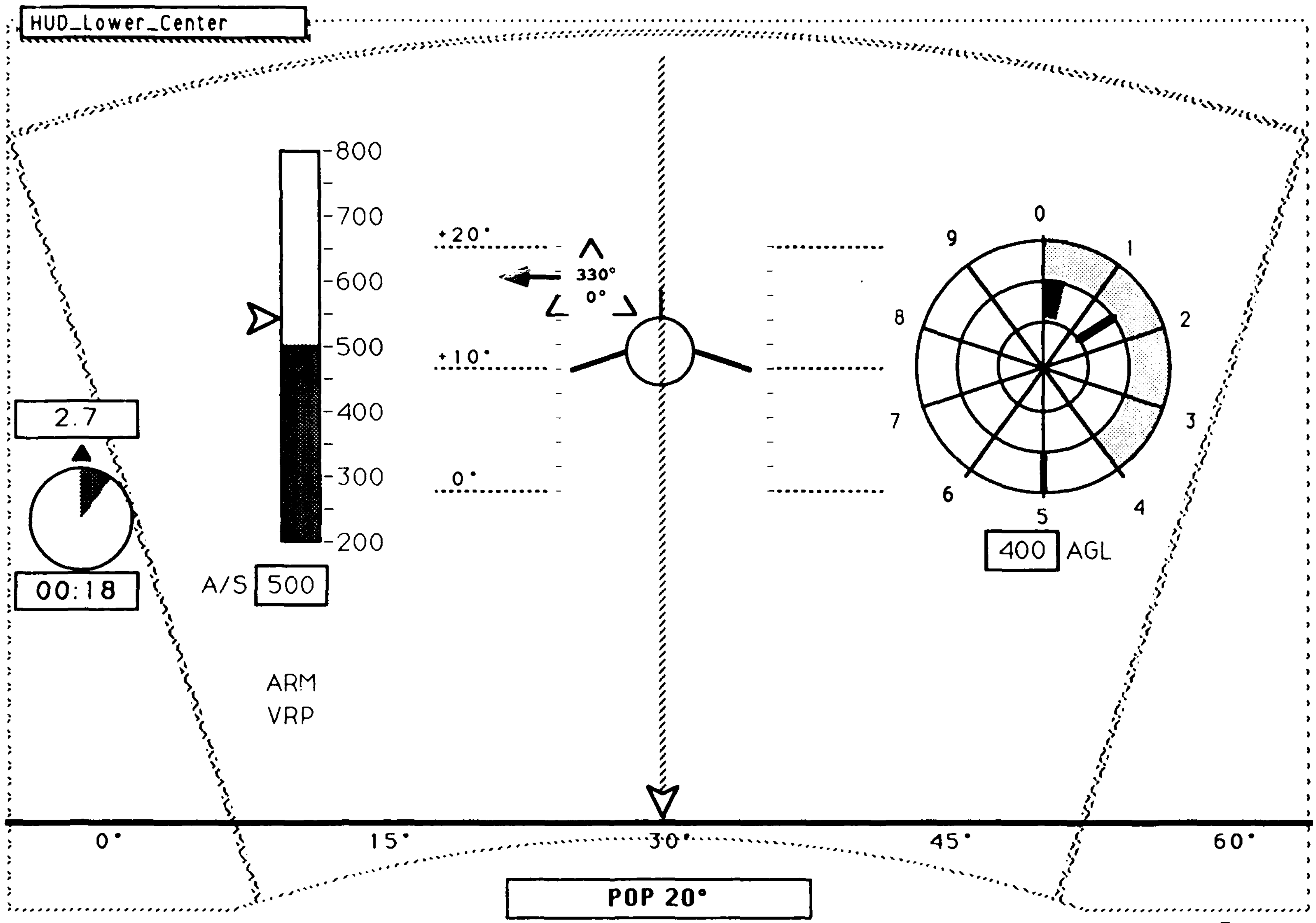

HUD_Lower_Center
330°
345°
0°
15°
30°
-800
-700
-600
-500
-400
-300
-200
540
A/S
ARM
VRP
+10°
0°
-10°
15.0
01:40
0
1
2
3
4
5
6
7
9
200
AGL
ALL SYSTEMS OK

Frame 3

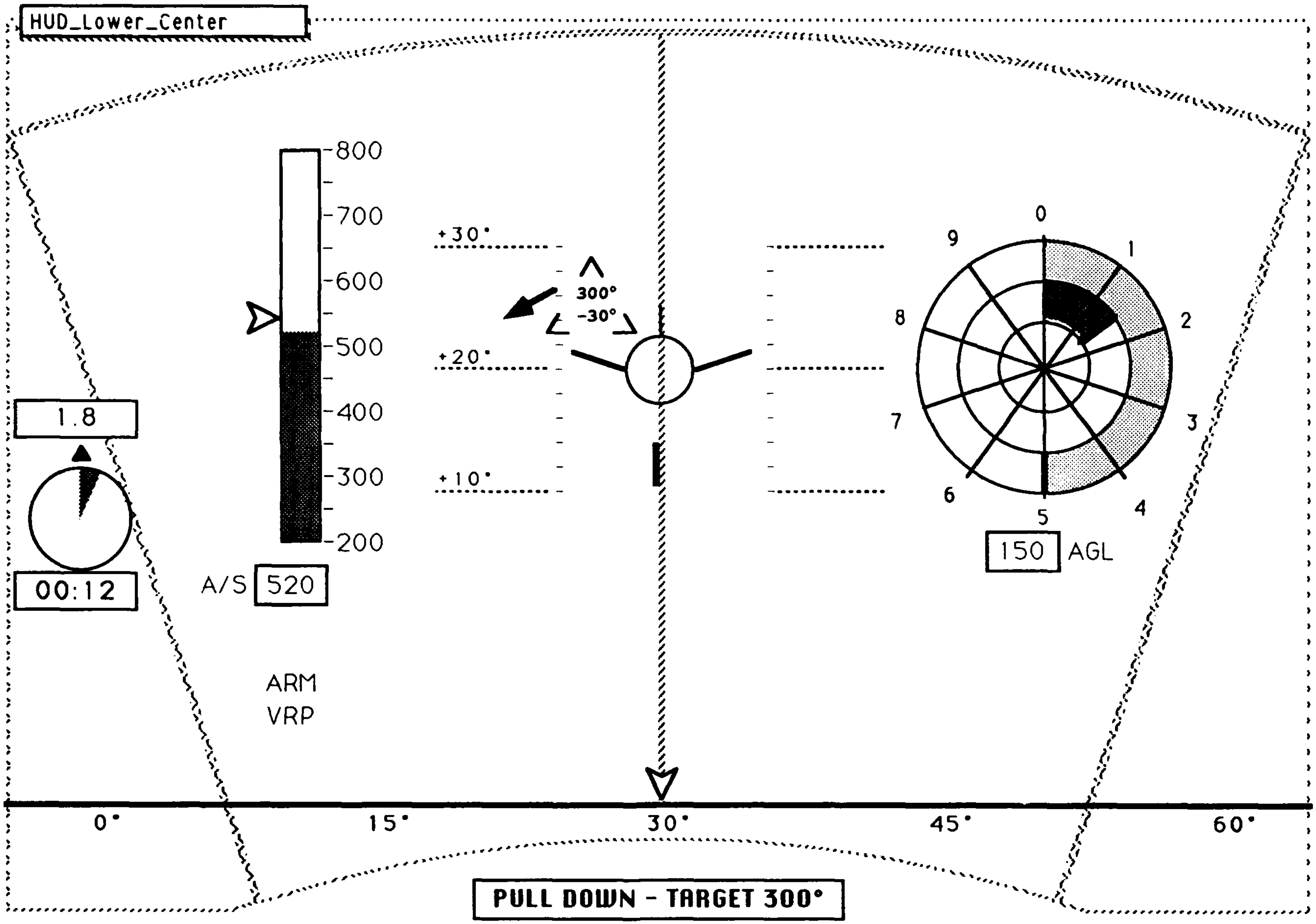

HUD_Lower_Center
800
700
600
500
400
300
200
A/S 540
+10°
0°
-10°
0
1
2
3
4
5
6
7
8
9
200 AGL
4.1
00:27
ARM
VRP
330°
345°
0°
15°
30°
ACTION RIGHT 30°

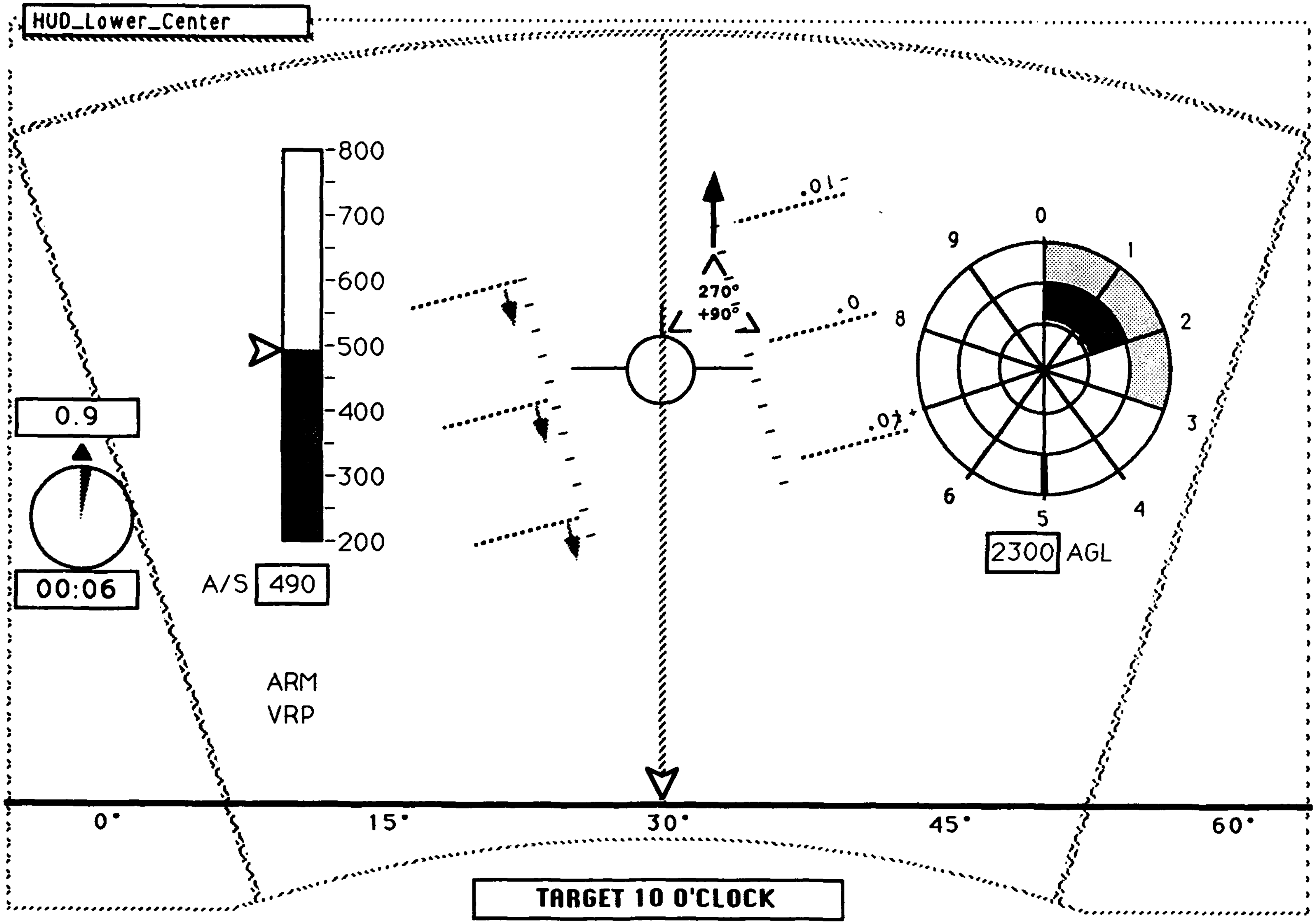
Frame 4


HUD_Lower_Center
800
700
600
500
400
300
200
A/S 540
+10°
0°
-10°
0
1
2
3
4
5
6
7
8
9
200 AGL
ARM
VRP
3.6
00:24
0°
5°
30°
45°
60°
POP 20°
Frame 5

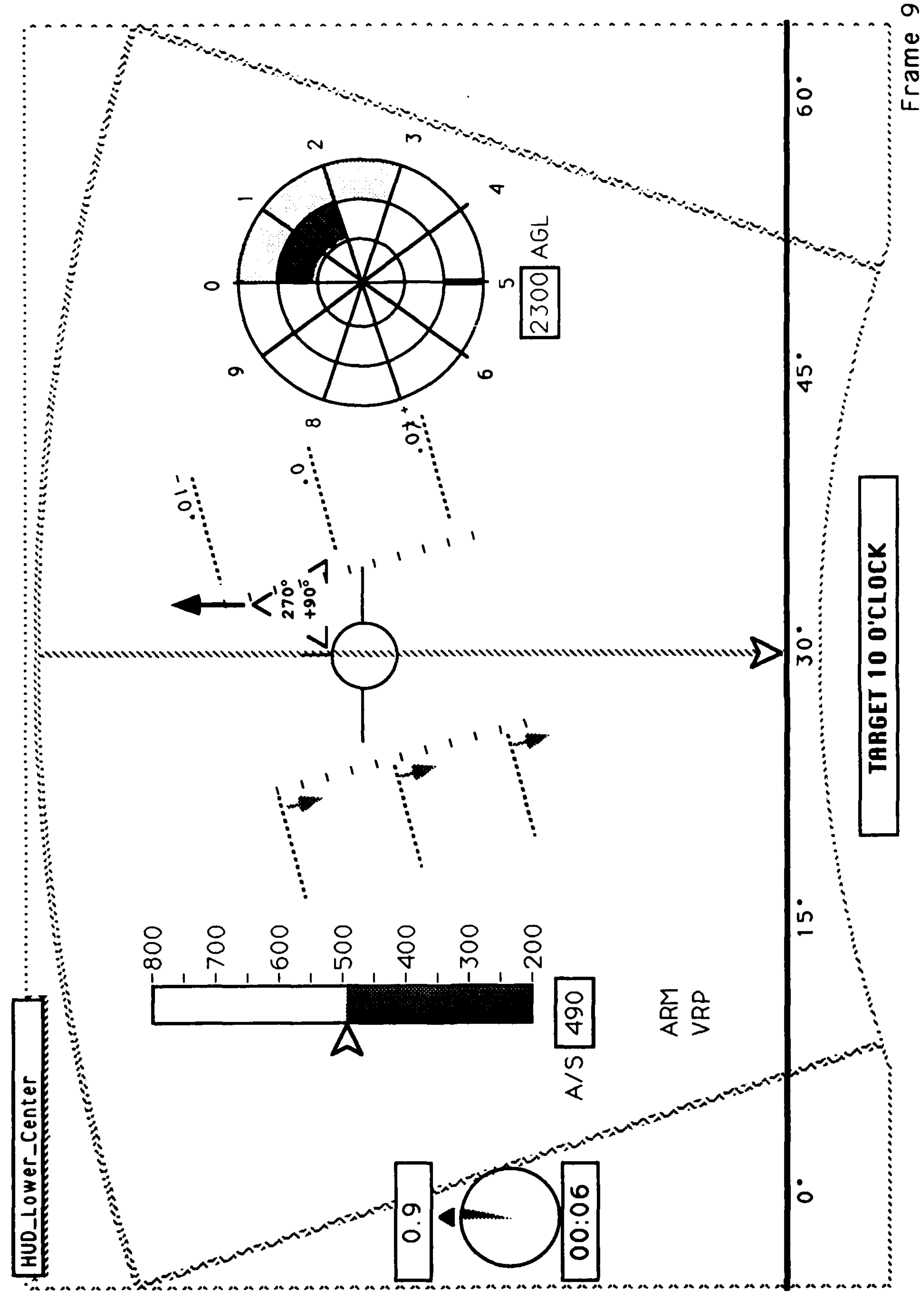

HUD_Lower_Center
800
700
600
500
400
300
200
A/S 500
2.7
00:18
ARM
VRP
+20°
+10°
0°
330°
0°
0
1
2
3
4
5
6
7
8
9
400 AGL
0°
15°
30°
45°
60°
POP 20°

Frame 6


HUD_Lower_Center
800
700
600
500
400
300
200
A/S 520
1.8
00:12
ARM
VRP
+30°
+20°
+10°
300°
-30°
0
1
2
3
4
5
6
7
8
9
150 AGL
0°
15°
30°
45°
60°
PULL DOWN - TARGET 300°
Frame 7


HUD_Lower_Center
0.9
00:06
800
700
600
500
400
300
200
A/S 490
ARM
VRP
270°
+90°
10
0
10
0
1
2
3
4
5
6
8
9
2300 AGL
0°
15°
30°
45°
60°
TARGET 10 O'CLOCK

Frame 8



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